The Idea of Science dominates the modern world. However, the nature of science – what science really is – has been quite elusive. Science is commonly associated with themes like truth, logic, rationality, objectivity, knowledge and genius. But how far are these common beliefs about science really true? This book is a way of thinking about science, primarily from a philosophical perspective. It also introduces specific Indian paradigms which are relevant to understanding science. The book covers a vast range of topics ranging from logic to ethics in the context of science. It should be of interest to those who desire to understand science in all its complexity, strengths and weaknesses.

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What is Science?

SUNDAR SARUKKAI

POPULAR READERS' SERIES

What is SCIENCE?

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WHAT IS SCIENCE?

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For
my father, S. K. Rangarajan,
whose absence remains an enduring presence, and without
whose inspiration this book would not have been created
&
my mother, Santha,
for teaching me much more than texts ever could

Contents

Preface

India's 'tryst with destiny', a phrase used so powerfully by Pandit Nehru, was, and is, actually a tryst with science. For Nehru, this equivalence would only have been welcome. His belief that industries were the temples of modern India and his support for the larger State project of science are indicators of this. Political freedom from the British would lead to intellectual freedom of the citizens of India through the use of science. And since science was universal and not associated with any country as such this liberation was indeed a model of universal freedom. One is thus not answerable to any individual or even any tradition but only to one's 'universal' reason. Although Nehru did not articulate his vision in exactly this manner, the emphasis on science immediately after independence suggests how our leaders bought into this picture of science. This is also radically reflected in the Indian constitution: one of the duties of the Indian citizen is to 'develop scientific temper'. None of the other countries in the world have this constitutional duty to possess a scientific temper. Not even the most advanced scientific societies expect this from their citizens! And this for good reason – to expect that citizens should inculcate scientific temper is to reduce science to a variety of common sense and also to ignore the fact that humans, in general, cannot be 'scientifically rational' in the decisions they make. This rationality is only one particular kind of rationality.

The birth of modern India is immersed in such confusion and hope: confusion about how to inherit the various kinds of traditions

and hope that science would be the path towards a new era. In principle, it was also going to be an impossible task. Primarily this was because of the confusion engendered by the use of the word 'science'. The idea of science that influenced these minds was not one that comprised disciplines such as physics and chemistry but was more a worldview which had the characteristics of rationality, logic and reason underlying it. It is possible to believe that the seduction of science in this moment of the birth of an independent India was not to be found in industries and technology. There was a purity and innocence about this belief about science, a state which can be found in a dominant section of the scientist population in India today. It has also become a part of a cultural response (rather non-response) to matters of science in the country. If, in other countries, scientific establishments have come under the scrutiny of the public, here they continue to remain isolated pockets with little social accountability.

Much has changed in India in the years after independence. And much has also changed in the way we understand science. In this intervening period, science and technology studies which include disciplines such as history, philosophy and sociology of science and technology, have helped us understand the nature of science and technology in much more sophisticated ways than possible earlier. In the Indian context, these issues are further enhanced by scholarly works on science and technology in ancient and medieval India. Along with this is the strong body of work on rational Indian philosophical traditions, including the seminal contribution to logic by Indian logicians, all of which question naive images of science that first influenced the development of the Nehruvian vision.

Thus, the appropriate question to begin with is this: What – exactly – is – science? What exactly do we mean by science? For most of us, we first hear of science in the context of subjects we study. In school, science is taught as one subject before we study individual subjects such as physics, chemistry and biology. Interestingly, this is exactly the opposite of what happened historically.

This book attempts to define science. Science, in the public

imagination, is deeply associated with the notions of logic, rationality, truth, knowledge and intelligence. This book re-looks at these assumptions not by denying them but by showing how complex science really is. This complexity negates any simple definition of science. The first chapter attempts to illustrate the different ways in which we use the word 'science'. For the general public, 'science' and scientists often become synonymous. Indeed, a large number of people believe that science is really what scientists do. So in order to understand science it is necessary to see what scientists do and how they do it. The second chapter describes what scientists do, both in their regular day-to-day work as well as in their scientific activities. Perhaps the most entrenched opinion about science is that it is logical. This catalyzes the widely held belief that scientists are always logical even when they are not doing science. The third chapter analyses the relation between science and logic. To understand this relation, we need to first know what logic means. This chapter introduces the reader to some basic themes in logic, including Indian logic, and illustrates how the latter may also be useful in understanding the nature of science.

More than any other discipline, science has an extremely vibrant engagement with the theme of reality. Science opens up new realities through its instruments. We believe in the reality of atoms, electrons and quarks; of genes and DNAs; of polymers and proteins, and so on. The fourth chapter illustrates the complex character of reality which is described by science. Reality also grounds our beliefs in truth and knowledge. We have different kinds of knowledge such as moral knowledge, religious knowledge and knowledge needed for daily living. Scientific knowledge is a special type of knowledge. The fifth chapter deals with the notion of scientific knowledge. This chapter also discusses the special role of mathematics in the sciences.

Science has had a troubled relationship with the human subject. Science is seen to embody the virtues of universality, of emphasising reason as against emotion, having no cultural or historical bias, and so on. The sixth chapter explores some of these themes, including the claims to the multicultural origins of science. This chapter ends with

a long discussion on ethics and science. The last chapter summarizes some reasons for the successes of science as well as its limitations.

Without any doubt, this book represents an idiosyncratic interpretation of science. The topics were chosen in order (1) to critically understand the standard views about science particularly its relationship to logic, reality, knowledge and the human subject, and (2) to illustrate the complexity of the activity of science which does not let us reduce science to clear and simple categories. In so doing, I am aware that I may not have answered the question 'What is Science?' in the way a scientist or historian of science or even a sociologist of science might have done. But I do believe that the book will open up multiple ways through which we can think about the nature of science.

Since this is an introductory book, I have avoided an academic style of writing in general. There may be a few sections here and there which might be difficult on a first reading. The reader can skip these sections and come back to it later. I hope that this book will inspire students and others interested in the nature of science to inquire more carefully and deeply into the naïve assumptions about science. I also hope that this book will interest scientists and give them sufficient tools to understand the foundational nature of the activity of science. This book is also targeted at the large number of students and professionals in social science, humanities and arts in the hope that they will be able to engage with the institution of natural science with more awareness and confidence.

* * *

Some of the material in this book has earlier been published in various places. In Chapter 3, the section 'Where is logic to be found in science?' is extracted from Sarukkai, 2005, *Indian Philosophy and Philosophy of Science*. Another section 'So how logical is science? The role of beauty in science' is extracted from Sarukkai, 2004, *Philosophy of Symmetry*. The section 'Science and Indian Logic' is an edited and condensed extract of the Introduction chapter of Sarukkai (2005).

I thank the publisher, Center for Studies in Civilization, Delhi, for permission to reproduce these few pages.

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In Chapter 5, the section 'Language and knowledge: The special place of mathematics in the sciences' is an edited version of the paper titled "Revisiting the 'unreasonable effectiveness' of mathematics" published in *Current Science* 88, 2005. In Chapter 6, the section 'Science and the ethics of curiosity' is a slightly edited version of the paper of the same title published in *Current Science* 97, 2009. I thank the Indian Academy of Sciences for permission to use these papers in this book. In Chapter 6, the section 'The multicultural origins of modern science' is a slightly expanded version of the book review of Arun Bala's book published in *Philosophy East and West*, 2011. I thank the journal and their Editor, Roger Ames, for permission to use this material in this book.

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SUNDAR SARUKKAI

I

Defining Science

Article 51A(h) of the Constitution of India

FUNDAMENTAL DUTY of the Citizens of India: *'To develop the scientific temper, humanism and the spirit of inquiry and reform.'*

In a public lecture at the Indian Institute of Science, Bangalore, in January 2010, David Gross, the celebrated theoretical physicist and winner of the Nobel Prize for Physics in 2004, narrated an interesting incident in the life of John Nash. At the press conference held shortly after the announcement of the 'Nobel Prize' for Economics (the official name of the prize is the Sveriges Riksbank Prize in Economic Sciences), a journalist asked Prof Nash the following question: Since the prize was given for economic science, did Nash agree that economics was a science? Nash apparently replied that any subject which needed to have the appendage 'science' to it could *not* really be a science. Gross then went on to say how the disciplines of physics, chemistry, mathematics and biology did not have the addition of 'science' to them whereas 'social science' did. Like most other scientists he seemed to be quite dismissive of the claims of science in social science.

Two hundred years ago, a similar question of what defines science was hotly debated in Europe. In the early 1800s science was not the dominant profession in Europe, particularly Britain. Subjects

such as theology and classics had a greater status in society. Science did not enjoy the cultural prestige that it came to have later on. There was no well established notion of 'being a professional' and the 'scientist' of those times moved between science, theology, political economy and even literature. While there was some acceptance of the view that science meant systematic knowledge yet the scope for confusion remained since subjects like logic, theology and grammar were seen not only as sciences but often were used synonymously with philosophy. Before the use of the word 'science' to refer to subjects like physics and chemistry, the common terminology for them was 'natural philosophy'. And if science was seen primarily as a study of nature then there were different professions which did it—astronomers, chemists, botanists and geologists. This proliferation of subjects led Babbage to complain in 1851 that "our language itself contains no *single* term to describe these various occupations". A similar point was made by Whewell in 1833. Although Whewell coined the term 'scientist' in 1833, it was not widely accepted by the 'scientific' community till the end of the century. People like Faraday and T. H. Huxley thought that their work (in science) was part of a broader framework which included philosophy, theology and morality (Yeo 2003).

The establishment of science as a separate discipline needed a conscious effort at 'popularizing' science. Part of this process was catalyzed by a rivalry between France and Britain, and the increasing role of science within these States. But we should note that the popularization of science is not to be understood as we do now since there was no clear distinction between 'expert scientist' and 'lay audience' at that time. The proliferation of Victorian periodicals, which played an important part in bringing science to the society and legitimizing it, were those in which both the 'experts' and the 'lay' wrote and debated.

So what Gross said in 2010 is nothing new. In fact, this problem is more acute now than it was two or three centuries ago. The reason is that there is a much greater proliferation of subjects under the common category of science. If we look at the list of subjects which fall under science today it is no longer physics, chemistry, biology or geology. First of all, each one of these subjects has many specialised disciplines under them. Within physics there are many sub-disciplines, some of which include astronomy, condensed matter physics, particle physics, nuclear physics, laser physics, classical physics and quantum physics. Under chemistry there are disciplines like electrochemistry, organic chemistry, inorganic chemistry, stereochemistry, polymer chemistry and synthetic chemistry. Biology has another long list of sub-disciplines including cell biology, molecular biology, genetics and more traditional subjects such as botany and zoology. A general list of science subjects taught in universities today includes marine science, environmental science, management science, health science, medical science and library science. Some academic institutions offer a course on 'wine science'!

Both Gross and Nash are wrong in their interpretation of the implication of adding 'science' to the name of certain disciplines. As we see in the specialized disciplines within physics, chemistry and other science subjects, most of them have the attached tag of 'physics', 'chemistry' and 'biology'. For example, 'condensed matter physics', 'particle physics' or 'nuclear physics' all have the term 'physics' attached to them. One cannot extrapolate Nash's comment to say that any subject that adds the term 'physics' to it is not really physics! The reason for adding the term 'science', just like the addition of terms like 'physics', 'chemistry' and 'biology', is historical and indicates a kind of family kinship.

Nevertheless, looking at the huge list of subjects which are now listed under science, we are naturally compelled to ask why they are all called science. What is it within each of these disciplines that makes them subjects of science? Why are they not subjects of 'art' or 'literature'? This is exactly the point that Babbage was making when he pointed out the apparent lack of common elements in the occupations which studied nature.

But in a way Nash is right when he is dismissive of subjects

which have the word 'science' as an appendage. Much earlier, in the West, they used philosophy in a similar manner when subjects of science were called 'natural philosophy'. In the early days of scientific disciplines, there was value in relating them to an established and respected discipline like philosophy. Similarly, it is the case that some disciplines found an advantage in being seen as a science because of the cultural and social prestige attached to it. Science was also strongly supported by the State and more money was available to those fields within the sciences. Since contemporary culture places value on those who do science, people who work in some disciplines presented themselves as scientists. Thus, subjects like management studies became management science; ecology became ecological science and so on. Even a subject that studies the art of wine making and tasting is presented as 'Wine Science'. In India, we have a unique subject, one which is also extremely popular, called Home Science. Confronted with this phenomenon it is indeed reasonable to ask the question 'What is science?'

There are no easy answers to this question. Unless we know what we mean by science we cannot say whether a particular subject is a science or not. On the other hand, we do not really know what a science is but only know the different subjects that are usually called science. In the remaining part of this chapter, I will explore the different possible meanings of 'science'.

But first, on the etymology of science. Science is derived from the Latin word *scientia,* meaning knowing. In the western context, 'science' comes into general use after 1300 AD and was primarily understood as knowledge acquired by 'study'; it also included studies of art. It is only in the 18^{th} century that some notion of method was attached to 'science' but in this period philosophy was also seen as a methodological study which led to knowledge. As mentioned earlier, what we call science was first referred to as 'natural philosophy'. The use of the word 'science' has a complex history and is associated with various factors. There are many different meanings of 'science'. I will list these various possibilities

and consider the different ways in which science is understood in each of these meanings.

Science as a Concept

When we see a mango tree we classify it as a tree. In doing so, we are placing a particular tree under the general concept of a tree. When we classify disciplines as belonging to science we are similarly doing this job of classifying them under a concept called Science. This is what we do when we classify physics under science – we place a particular subject called physics under the larger category called science. So also for all the other subjects which are classified under science. Understanding science as a concept at least helps us explain what we are doing when we call some subject a science. We do a similar job of classifying when we identify certain elements such as scientific methodology and scientific way of thinking as belonging to the nature of science (and not the subject of science). In all these cases, we recognize some characteristic of science that is present in different subjects and different types of activities.

Philosophically, there are many issues surrounding this propensity for classification. Consider the example of a 'dog'. Many different types of dogs are classified under the category dog. We place an Alsatian in this category and also the Tibetan Terrier. Why do we put all these different types (which runs into hundreds) under one category called 'dog'? It cannot be because all of them have four legs since countless other animals also have four legs. One cannot say that they all 'look' like dogs – this too is not correct since some dogs, like the Alsatians, look more like wolves and some look more like cats!

Classification is one of the most fundamental activities of the human mind. Stereotyping and generalizations about people and communities often involve categorizing. Categorization is also very economical. Suppose you were asked to list all the objects in a class room. One could list them by naming each of the chairs or one could say that there are '45' 'chairs' in the room. In the case of the latter, we create a concept called chair under which we put each one of

the chairs. (Note that in this case we also have another concept, the concept of a number under which belongs a particular number 45.) So when we have a proliferation of things we can use categories to have an economical description. In this sense, categories are not as much about truth as about making it easy for us to talk about objects, to make sense of similarity and so on. However, almost all cases of categorization have a problem: that of specifying why something is placed under a given category. Some philosophers have used the idea of essence to respond to this issue. All trees – however different they may look – are classified under trees because they have the essence of 'treehood' in all of them. The idea of essence is debatable and philosophers have held different views on essence. However, in common usage, we do tend to make sense of categories through some notion of essence.

The use of the word 'Science' is somewhat similar. It is a category under which a variety of things can be put. This does not mean that everything within it (i.e. everything called science) is exactly similar to each other. Just as members of the category of dog differ in many of the characteristics so too do members of the category of science. Following some classical traditions in both Indian and Western philosophy, we might argue that since a category has an essence or essences we could say that anything which is a science has an essence or essences related to the category Science. In fact, the word 'scientific' is something like an essence. You can be scientific in a number of activities and disciplines. Being scientific is a mark of something which can be put under the category science. The problem then is to specify what scientific really means and it is not clear whether this is less difficult than specifying what science means.

Although there are problems, science as a category is a reasonable description of how the word science is used. When we put disciplines such as physics, chemistry, biology into a category called science we are recognizing that these are loosely related to each other. One way to describe this is by using the idea of family resemblance, an idea made famous by the philosopher Wittgenstein. Disciplines grouped

under science, including 'Wine Science', 'Management Science' and 'Home Science' are related to physics, for example, in the way members of a family are related to each other. In family resemblance, there is no strict similarity. So what exactly characterises a family if not similarity? Families are *related* to each other and it is the kind of relations (biological and natural) that specify family membership. Thus, when somebody claims that physics and wine science belong to the same family called science, perhaps they are only suggesting that there exists some kind of a relationship between the two. Most often when disparate subjects are called science there will be some attempt to relate them through common methodology or common assumptions such as the rejection of supernatural forces to explain the natural world.

So what we have done by looking at science as a category is to replace the question of similarity between diverse subjects and activities that are placed under science with the idea of relatedness as in a family. But this does not solve the problem of what to do when new members claim relationship with the family. These new members might make this claim because being associated with the family of 'science' gives them greater benefits. This is like some people who claim to be descendants of monarchy in various countries. Science as a category or family cannot help us to decide these kinds of cases. In important debates about astrology, alternate medicine and so on, this is really what is at stake.

Science as a Title

While science as a category explains some aspects of the distribution of subjects that are put under science, it still does not explain the constant struggle in accepting or rejecting particular subjects and activities as science. For example, most scientists do not accept astrology as a science. Many of them do not think social science is a science. The problem seems to be that some members aspire to belong to a category but they are not allowed that privilege.

In the case of trees and dogs, this does not seem to be a problem

(although one should not take this for granted). That is perhaps because these categories are natural, what philosophers call as 'natural kinds' – kinds of things which occur in nature. But there are also artificial kinds, that is, groupings created by us. For example, family is itself a social category. Nation is another social category. Under the category 'nation' we have many nations just like under the category 'dog' we have many types of dogs. But note that somebody has to agree whether a particular place is indeed a nation or not. Many communities routinely claim the status of a nation – look at the number of freedom movements in this world at any given time! But just because somebody says their 'place' is a nation it does not make it a nation. Somebody else has to give the sanction for it; if the local government doesn't then international organisations like the UN could perhaps attempt to do this. But we all know how difficult and dangerous this activity of sanctioning new nations can be.

The point is that 'science' is a lot like a 'nation'. The analogy between science and nation is quite strong. The first is that science is intrinsically associated with an authority which will designate what is science and what is not just like some institution will decide whether a particular entity is a nation or not. In this sense, science is like a title of nationhood which is bestowed by some authority. While very often there will be good reasons for accepting or rejecting a claim to nationhood, there may be borderline cases where it is difficult to decide.

Understanding science through this analogy of a nation also allows us to understand the relationship between the members of the group called science and science itself. Consider the idea of citizenship. If we want to call somebody an Indian, that is, put a person into the category 'Indian', then we expect that person to fulfil certain conditions. If we look at all the members who belong to the category 'Indian' we find very diverse members. So just because we are all Indians it does not mean that there is some common property that we all share that allows all of us to be put under one category. As is well known, it is very difficult to identify common characteristics among all Indians!

So instead of looking for common properties, we might want to claim that every person who lives in India is an Indian but this claim is unhelpful on at least two counts: firstly, citizens of other countries live in India (this includes tourists also) and secondly, Indians live outside India too. One might then say that those who have an Indian passport are Indians – but then this excludes millions of Indians who do not have passports. If we try religious and cultural definitions of being Indian then the project is near hopeless since it is almost impossible to find commonalities between all individuals who are Indians. Yet, we have a workable category called Indians. The category of Indian is largely based on a legal framework, such as those possessing Indian passports, ration cards and so on. The point here is that being an Indian is a title, a 'legal title' bestowed by the government of India on its citizens. The point about titles is that the person who bestows the title has the final say in the matter of classification. (Even in the case of cultural claims of Indian-ness, remember that the problem is that some group or the other will claim that some are not 'Indian', because of their social and cultural practices, although they live in India.)

Could it be that 'science' is actually a title that is bestowed upon a discipline or activity? Just like the folk saying that science is what the scientist does, so also can we say that science is the title that scientists bestow on others? That is, whatever activity is dubbed as science by the scientists becomes science. We can see this very clearly in many of the debates about which disciplines should be called a science. The case of the social sciences is a reminder about how science functions as a title. Many scientists from the natural sciences do not accept social sciences as a science even though social scientists (as the name itself suggests) call themselves as scientists. Ultimately, how do we adjudicate between these two communities? For example, there are many who believe that the essential mark of science lies in the use of mathematics. This means that unless sociology or anthropology uses mathematics then they will not legitimately be called a science. If so, then the scientists are functioning like the government of India

in that they decide to give the certificate of science to those who they think satisfy their criteria for being a scientist. This explicit control over the title of science is very much a part of the problem of defining what science is. The institution of science in fact is like the government and decides what is a science and what is not. (Just like in the case of the nation, conflicts about national identity arise only at the borders when one is attempting to move either into the country or outside the country – when subjects want to enter into the club of science or leave the club.)

Thus, it is not a surprise to see various academies and societies of science in different countries routinely coming out with a statement defining science. Here are some examples. The American Physical Society defines science as follows (as adopted in 1999).

> 'Science extends and enriches our lives, expands our imagination and liberates us from the bonds of ignorance and superstition. The American Physical Society affirms the precepts of modern science that are responsible for its success.
>
> Science is the systematic enterprise of gathering knowledge about the universe and organizing and condensing that knowledge into testable laws and theories.
>
> The success and credibility of science are anchored in the willingness of scientists to:
>
> Expose their ideas and results to independent testing and replication by others. This requires the open exchange of data, procedures and materials.
>
> Abandon or modify previously accepted conclusions when confronted with more complete or reliable experimental or observational evidence.
>
> Adherence to these principles provides a mechanism for self-correction that is the foundation of the credibility of science.'

The Science Council in Britain, another influential body in Britain, also attempts a formal definition of science. It is worthwhile reading the reasons for this attempt:

> 'The Science Council has 'science' in its name but had not previously clarified what this actually meant. In addition to developing a better understanding of what types of organisations might become member bodies, it was felt that the recent inclusion of the advancement of science as a charitable activity in the 2006 Charities Act suggested that in that context a definition would be useful; and finally, the Science Council agreed that it wanted to be clearer when it talked about sound science and science based policy what it was actually describing.'

Here is a body of scientists, whose purpose is, in their own words, to 'provide a collective voice for science and scientists and to maintain standards across all the scientific disciplines.' It is important to note that even after all these centuries of doing science and having powerful scientific institutions this Council feels that the meaning of 'science' has to be clarified even now. The avowed purpose is to unite scientists together and also to act as a guardian against misappropriation of science. In other words, organizations like this will bestow the title of science since they decide 'what types of organizations might become member bodies.' Since financial support for science is necessary from the government, such attempts are also a way to make sure that there is enough allocation of resources to science related activities as well as making sure that activities which do not fall into the category of science do not appropriate the name of science in order to attract resources or legitimize themselves.

If science is understood in this manner then we can begin to understand the various kinds of conflict between science and non-science. Given that the title of science has value in the present times, it is only reasonable to expect spurious claims to science-hood. Centuries ago, in the beginning of modern science, it was religion or philosophy which had this value and physicists and mathematicians often invoked the idea of God or of religion to validate their work. The classic example of this is Issac Newton who tried to get legitimacy to his physics by claiming that the success of

his physics proved the existence of God! Now the roles are reversed and religion, often, tries to legitimize itself by saying its claims are scientific or that what religion talks about has some correlation with modern science.

Science as a Method

One might ask whether there are other criteria which can help us understand what science is. One such criterion is the idea of method. The claim here is that science is characterised by a special method, the scientific method. The essence of science is this scientific method.

This is a view that has many supporters and in fact is a common way of distinguishing science. Here are some examples of definitions of science which draw upon the idea of method.

> '...science is a systematic method of continuing investigation, based on observation, scientific hypothesis testing, measurement, experimentation, and theory building, which leads to explanations of natural phenomena, processes, or objects, that are open to further testing, revision, and falsification, and while not 'believed in' through faith are accepted or rejected on the basis of scientific evidence.' (The Ohio Academy of Science)

The definition of science is not only of interest to professional science bodies. Even courts have often been called upon to define science. For example, the US Supreme Court (1993), in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, defined science as follows.

> 'Science is not an encyclopedic body of knowledge about the universe. Instead, it represents a *process* for proposing and refining theoretical explanations about the world that are subject to further testing and refinement. But, in order to qualify as 'scientific knowledge,' an inference or assertion must be derived by the scientific method. Proposed testimony must be supported by appropriate validation—*i.e.*, 'good grounds,' based on what is known. In short, the requirement that an expert's testimony pertain to 'scientific knowledge' establishes a standard of evidentiary reliability.'

> The Science Council in Britain defines science as follows:
> 'Science is the pursuit of knowledge and understanding of the natural and social world following a systematic methodology based on evidence.'

Many historians and philosophers of science also understand science as a method. Although the idea of a coherent and uniform scientific method common to all disciplines of science has been challenged there are nevertheless good reasons for believing that science is characterised by a special method. This method is, in the most general sense, defined by the union of experiment and theory. Scientists do experiments and based on data they infer about a variety of things in nature. This is a simple picture but yet very influential. Later on, when we discuss in greater detail this idea of scientific method, we will see how much more complex this picture really is and that even the very notions of experiment and theory are not simple at all.

But, for now, can we say that scientific method satisfies the search for a definition of science? It is not possible to say so because on the one hand, the integration of theory and experiment is common to various other human activities (in fact, I would say that it is common to most of everything we do) and on the other hand, the meaning of theory and experiment themselves are different in the various disciplines of science. For example, one important marker for theory has been the use of mathematics. Now there are various branches of science which do not depend on mathematics either in the way physics does or only use mathematics in a minimal sense. Do we then say that these disciplines are not scientific? Moreover, how do we distinguish the idea of experiment in art and cooking, to give two random examples, against experiments in physics, chemistry and biology? Is it possible to come up with a consistent distinction?

One way to do this is to give a more rigorous definition of theory and experiment by considering what is special to scientific theories. Here is one way to characterise the uniqueness of scientific theories: they are unique because not only do they describe but they also explain. Moreover, the character of scientific explanation is itself unique (more on this later). Scientific theory also creates and uses many new concepts which are not available in ordinary descriptions. In fact, invention of scientific concepts is a special characteristic of good science. Scientific theories do the job of unifying, that is, they discover commonality in diverse phenomena. Most often, at least in the fundamental theories of physics and partly chemistry, theories are mathematical in nature. Related to this is the discovery of laws of nature. All these are unique characteristics of theories in science.

What about scientific experiments? Is there something unique to them or is a cooking experiment similar to that of a scientific experiment? Scientific experiments today – like scientific theory – are very specialized and needs sophisticated technology. Scientific experiments not only test but they are far more dynamic – they intervene in nature and show a great degree of manipulative skills. They are able to manipulate nature much more than any other model of experiment which may be present in various other activities such as art, cooking and so on.

And finally, the relation between theory and experiment is also unique to science. This relation is associated with the ideas of verifiability and falsifiability. This relation has also been understood to be a logical relation – that is, the move from observation and evidence to theory and the relation between the theoretical and the experimental often has the structure of a deductive argument. However, the very notion of a theory is different in different scientific disciplines. The theories of physics are quite different from biology, which in turn are quite different from computer science. So also in the case of experiments. Laws in physics are not like laws in biology. What chemistry does in an essential sense is to synthesize and create whereas physics is best known for its ability to analyse and

describe what is already present in nature. Similarly, the distinction in method and theory between science and engineering is also quite striking.

However, although there might be some problems in identifying science uniquely through a scientific method, it is nevertheless a useful way to characterise science. Over the next few chapters, I will discuss the various contours of scientific method.

Science as a Criterion for Demarcation

Merely by adding the term 'science' to a discipline does not make it into a science. Something else has to be the case and in Popper's view it was the emphasis on the criterion of falsifiability. Karl Popper's model of science was this: scientists make hypothesis and then deduce the consequences of these hypotheses. These hypotheses are such that they are open to being falsifiable, that is, open to being shown to be wrong. A good scientific assertion should allow for the possibility that it could be wrong and there should be ways to show how it is wrong. Popper's argument was that verifiability is not a proper criterion for science. Very general statements can often be easily verified. Consider the prediction that it will rain. This prediction is always true since it will be raining somewhere or the other. Such statements are easily verifiable but are not really scientific statements. To qualify as one, there has to be more 'empirical content'. For example, the statement that 'It is going to rain in Manipal' is less general than 'It is going to rain' but still not very specific. This statement will be always true since it doesn't say when it will rain in Manipal. But a statement like 'It is going to rain in Manipal tomorrow at 11 am in front of the post office' is an empirically strong statement. The strength of this statement is that it is open to being falsified, that is, open to being shown to be wrong. For Popper, scientific claims are like this, open to being proved wrong.

However, even with this view there are many difficulties. For one, scientists don't do science this way. Many scientific experiments are often attempts to verify various claims. Another problem is that

the relation between falsification and theories is far more complex than originally thought. Just because a consequence is falsified does not falsify the theory but only some elements in it. To discover which elements contribute to the problem is not an easy task. But in spite of these caveats, Popper's view has been very influential, at least among practicing scientists.

While Popper's claim about science could be seen as highlighting what is special to scientific method it was really inspired by his attempt to find criteria for demarcation between science and non-science. Falsifiability was used as the criterion which would help us judge whether something was a science or not. According to Popper, theories in physics were modelled on this aspect whereas in astrology or even psychology they were not based on falsifiability but on some general ideas of verifiability.

The question of demarcating science from non-science has inspired vehement debates about the nature of science because without knowing what science is one cannot really distinguish science from non-science. In this sense, the idea of science itself becomes a hallmark for demarcation. In so doing, science gets equated with truth, rationality, logic and so on which then become the criteria for demarcating science from non-science. The importance of the demarcation problem is seen in contemporary debates as to whether disciplines/activities such as astrology, ayurveda, folk medicine and traditional accounts of psychology, are scientific or not.

Science as Inquiry

Science, it could be said, is a particular kind of inquiry. But what is inquiry? When does a particular process become an inquiry? Is inquiry a method? A particular way of asking questions? Or something to do with how and what we doubt?

First of all, inquiry has a subject matter – the subject we are enquiring into. Typically, inquiry is a set of interrogative statements. Inquiring is to ask what and why questions. Scientists tend to believe that science has a special mode of inquiry. For example, The National

Science Foundation in the US emphasizes the importance of inquiry in doing science:

> '...When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills.'

Inquiry is seen to be the most basic of the human faculties involved in the process of any learning, and particularly science learning. Science teachers and science organisations that promote the teaching of science often echo the above views on inquiry. They believe that this mode of inquiry is common to both the students of science as well as practicing scientists.

Inquiry means 'search for truth'. The search for truth can be accomplished in many ways. Inquiry in science is one particular way with some unique characteristics. As we see in the definitions above, inquiry often begins with asking questions. Scientists often emphasise the importance of learning to ask questions, to have a questioning attitude. But what is a questioning attitude? It is true that we can ask questions of a variety of things. We can be sceptical of what we see around us, of what we are told by teachers and textbooks. Questioning is not merely an attitude to doubt everything. Questions can be for clarification; they can arise as part of an attempt to conceptualize, describe and so on.

Scepticism is one form of questioning where one doubts everything. Questioning is closely related to doubts. The importance of doubting in scientific inquiry should be noted. In the western tradition, it is most famously associated with the mathematician-philosopher, Rene Descartes, who made doubting the cornerstone of a scientific method. It is also a central principle in Indian

philosophical traditions, particularly the Nyāya school who had a very refined theory of doubt.

An important element of inquiry is the way it responds to authority. An inquiry should be impartial in the sense that it cannot be dictated by any kind of authority as far as its judgements are concerned. In principle, it is associated with the search for truth and is designed so as to uncover matters of fact. Although the attitude of inquiry is present in almost all other human endeavours including literature and arts, science – like everything else it does – institutionalises it well. Inquiry is made into a practice, a habit, a method. Good science is indeed associated with the practice of constantly asking questions and not being satisfied with answers even if they are given by eminent scientists. On the other hand, the kind of inquisitiveness that characterises this ideal image of science is more often than not practiced by many who are not professional scientists. So the appropriation of this mode of inquiry as something special to science can be challenged on two counts: one, that this way of looking at the world is indeed a common practice in other non-science academic disciplines and in practices like art; and two, scientists do not necessarily exhibit this spirit in their day-to-day work of doing science.

Science as Search for Truth

Science has an intrinsic engagement with truth. It is based on the belief that what it says about the world are the truths of the world. Scientists may accept that their truths are fallible, that is, probably wrong and potentially open to change. But given the knowledge at that moment, their assertions are about truths of the world.

Science's engagement with truth is interesting in the sense that it is less concerned about the nature of these truths or even why such truths hold. It is first of all concerned about discovering truths about nature. These truths could be about new particles such as quarks, new structures such as the structure of the atom, new relations such as universal laws, new material such as chemicals synthesized in the laboratory or creation of new materials in the metallurgical lab, new processes such as cloning and so on. Most often scientific truths are equivalent to facts of nature, facts that have to do with the capacity to intervene and manipulate the world.

Although philosophers find talk of truth troubling particularly because they have had great difficulty in understanding truth (there are many theories of truth in philosophy), scientists continue to associate truth with the activity of science. This has also been used as a way to demarcate science from other activities because, in this view, science is primarily an activity designed to uncover truth about the physical world. And in this science has succeeded like no other activity – it has indeed discovered countless facts about the world which were not accessible to ordinary perception or inference. Truth in science is closely related to the idea of scientific knowledge. I will discuss the larger issues surrounding truth and knowledge in the context of science in a later chapter.

Science as a Way of Thinking and Doing

Science has also been described as a particular way of thinking and doing, and is especially associated with 'critical' thinking. Critical thinking is often equated with logic and primarily it is a way of going from one thought to another in a reasoned manner. It also demands reasons for accepting any conclusion. It is way of thinking that is critical of any authority and believes that an individual has the capacity to reason for herself. A well-known physicist, Richard Feynman, whose writings on science and about science have influenced generations of students, in his speech about what is science at the National Science Teachers Association meeting in 1966, related science to observation and the capacity to think critically about these observations.

Science is also characterised by a particular way of doing. Although I had earlier mentioned that theory and experiment are often seen as two sides of science, the nature of experimentation was not clearly specified there. One influential image of scientists is that they are like children. Like children, they are supposed to have a

capacity to ask naive questions, to show great inquisitiveness about the natural world, to just tinker with things. Curiosity is seen as a virtue and scientists are supposed to be as curious as children are – that is, being curious without worrying about the consequences of being curious! Later in the book I will discuss in greater detail this idea of curiosity in science and the ethical consequences of it.

The spirit of experimentation is primarily that of tinkering with the world and with the objects at hand. Tinkering illustrates an act of curiosity to find out how a thing is made, how to put it back, what would happen if one 'played' with objects and so on. This hands-on tinkering is an important aspect of the scientific way of doing. Thinking is also a lot like tinkering. Scientists tinker with their thoughts in the sense that they take an idea and do things to it like one plays with things. Given an idea, like an object, they will attempt to see what kinds of presuppositions are hidden in that thought. They will also ask what will happen if they change one element of that idea just like they would attempt to see what would happen if they remove one part from an object. These constitute a method of doing science which is often referred to as 'thought experiments'.

So this is another way to define science – not necessarily in terms of concept, method etc., but primarily in terms of a special way of thinking and doing. This way is also characterised by a spirit of play and performance. This view of science is also a useful one for demarcation since other activities might not be defined so much by this attitude of tinkering. One important consequence of the process of tinkering is technology which is very much related to the attempt to tinker with nature in order to have better control over it and to harness its potential. In fact, many important technological discoveries are often made through tinkering and not – as is often presumed – from the application of a well-articulated theory.

Science as a Narrative

What we are seeing already is the multi-faceted nature of science. There are different ways of understanding what science is – they

are not all completely exclusive but each of these characterisations highlights some special characteristic of science.

There is another interesting way of understanding science. This view is not so much to do with doing science or how it functions in a society. It tries to understand science by what it says and the way it says it. In this sense, science is a narrative. It is a grand story of nature told by scientists. How a story is told is the narrative of that story. Science is special in the way it tells its stories. For example, there is a story about how an eclipse is caused because a snake swallows up the sun or the moon. We now call this story a myth suggesting that it is a story that is not based on facts. In contrast, we have another story – the story told by science as to how eclipses occur. This story is that when the moon comes in between the Earth and the Sun, the sun gets eclipsed. We call this story a scientific description because we believe that it is a true description of what happens in nature.

But primarily both myths and narratives of science are stories. But the way in which the story is told differs in myths and in science. The scientific narrative might be filled with attempts to explain, using other observations as evidence, making an argument for the phenomenon and so on. The mythical narrative might 'just' tell a story. Myths may also try and convince like a scientific narrative does but that is not their primary aim. Moreover, the images myths use will often be metaphorical whereas scientific narratives will primarily be literal – although we should note this is a claim that is questionable. (For example, the standard way of using straight lines to represent light rays is a metaphorical way of understanding light propagation and this image is very important to visually communicate the process of eclipse.) But nevertheless both are narratives – they are different ways of telling a story.

Often, scientists get upset when they hear science being described as stories. The reason for this response is that they mistakenly equate stories with falsehood. But, as we all well know, stories have a deep seated engagement with truth. Stories are a particular way of describing truth – scientific stories describes certain kinds of truth

in a particular manner and literature often describes other kinds of truths in a different manner. I will discuss this intriguing relation between truth and fiction in a later chapter.

Also, if we look at the complex stories told by science about the nature of our universe some of them seem like fiction! This is not to negate the importance of science; on the contrary, I think the capacity of science to come up with complex narratives in itself is its special strength. In fact, I would argue that science 'methodologizes' the capacity to tell stories – that is, a strength of the scientific method is to train scientists to make up innumerable stories. Which among all these stories is 'right' is a different matter altogether.

However, there are also special rules that characterise story telling in science. Some of the salient regulatory rules of scientific narrative are these: creation of special concepts (that are most often measurable concepts) in its stories (this is a powerful difference between 'ordinary' storytelling and scientific narratives); rejection of 'supernatural' elements in the story – that is, not invoking anything extra-natural, like the Divine, to describe natural phenomena; finding a structure of explanation within these stories – that is, along with the story various strategies of explanation also need to be present; no invocation of ultimate 'purpose' and in general no explicit use of philosophical or metaphysical issues in that narrative; the absence of an explicit author of the story thereby indicating a universality to the story. The bigger and grander narratives of science are also characterised by attempts to unify diverse phenomena and suggest predictable capacities present in that story. I will discuss many of these elements in the rest of the book.

Science as a Worldview

Scientists have, over the centuries, given their own version of what science is. C. V. Raman has this to say about science: 'What is science in the last analysis but the study and the love of nature, displayed not in the form of abstract worship but in the practical form of seeking to understand nature?' What scientists, as a group, as a community, say

about science is often different from what they say as individuals. For example, most scientists talk about science in poetic ways, ranging from the amazement and awe they feel to terms like love and worship (often of nature). We can see this in Raman's belief that science is the 'love of nature'.

In an earlier section, I had mentioned Feynman's description of science as a capacity to think critically. In that same talk, he also talks about the 'beauty and the wonder of the world' that is discovered through science. Most other scientists repeatedly refer to nature in these terms – when they are doing this they are not doing it as poets do but they are doing it as scientists.

In other words, science is a particular way of looking at the world. It could be in terms of awe, wonder and curiosity. It is mediated by inquisitiveness towards nature – wondering why the world is the way it is, why the sky is blue and so on. It is also characterised by a view of nature which science implicitly or explicitly holds.

Science needs a particular view of nature that will enable it to perform its activities. What I mean is that for science to do its tinkering – both in terms of thinking and doing, it has to first have a view on what nature is. And science has, either implicitly or explicitly, strong views on what nature is. First of all, nature for science is uniform. This uniformity is what allows experiments to be repeated, same observations to be made and so on. This is what makes scientists search for universal structures and universal laws. In other words, nature for science is stable, a characteristic which also makes it possible for science to manipulate nature.

Nature, for science, has to have no agency of its own – in particular, the agency associated with deception. That is, nature cannot decide what its properties should be or should not be. It is sterile in that sense. It cannot have the capacity to deceive in that it cannot present something as a fact only to change it later. To use a human term – nature cannot have any will of its own.

Scientists have for long believed in Galileo's description of nature as an open book which can be read by the scientists. The

consequence of this view is that scientists merely read off what is in the book and to be a scientist is primarily to have this capacity to be a reader of this book. Galileo complicates matters by saying that this open book is written in the language of mathematics and this perforce makes scientists know mathematics in order to read this book. This view of Galileo has had a profound impact on the development of science. I will discuss the question of mathematics later and here I will only draw attention to the special relationship science has with the question of language. The dominant worldview about language and nature that so much influences science is that nature has a special language in which it is best described. This special language can be mathematics but in recent times it also encompasses technical languages like computer languages.

Another view of nature that informs scientific activity is that nature hides its secrets which have to be ferreted out, sometimes with force if necessary. This view has led to disastrous consequences such as the enormous impact on the environment. Part of the problem lies in science's view that nature is mute, inanimate and we can do what we want with it in our search for its truths. Such a view allows science the liberty to break a homogenous world of nature into bits and parts in order to 'discover' its structure which then allows us to use its resources in a more effective manner. To really accomplish these tasks, science has to hold another problematical view about nature, namely, that humans are 'outside' nature. We are the observers of nature, we are the one who attempt to control nature and nature is out there for us to use as we see fit.

The point is that these views of nature are essential for science itself to be possible. These go on to constitute a larger worldview of science and are essential for its practice.

Science as a Means of Controlling the World

Related to science's view of nature is another special mark of it, which perhaps is the most defining characteristic of science – science not only describes the world in a special way, not only is its narrative

unique, it is also the case that it attempts to control the world. In terms of action and consequences, this particular attempt by science differentiates it most forcefully from other human disciplines.

None of the other human activities such as cooking, astrology, storytelling, art (some of which are seen to be similar to science in terms of narratives, knowledge-making, methods etc.) do what science does – attempt to control and overcome the limitations of the world. Even activities such as sports which inherently try and enhance the capability of the human body does not come close to what science does when it tries to overcome the limitations of the body. (Although we should remember here that there is a well-established discipline today called 'Sports Science'.) Humans cannot fly but through science we can.

In this sense, science is not just another story, another narrative, about the universe; it is also one that establishes control over it. It intervenes in the stories that it creates. Imagine if this happens in the field of literature – writers would write stories and they would also find ways to create their fictional world or change the existing world to fit their literary narratives. This intervention is what science does best. Some scientists create a new narrative of nature (most often they would be the theorists) and soon enough, if feasible, other scientists try to create that narrative in concrete terms. For example, when theorists developed a narrative of quarks as new fundamental particles, the experimentalists and the instrumentalists within the scientific community found ways to discover the concrete realizations of that narrative.

Most often this is quite difficult to do. Sometimes it looks as if it is 'easier' to come up with theoretical ideas but to make these ideas concrete often takes enormous time and effort. Much of the problem in doing this lies in the difficulty in controlling nature. But science finds it possible to control, manipulate and intervene in nature. By doing so, it can change nature in ways that can be quite radical. While some have suggested that social science intervenes and changes society like science does with the natural world, there is still

a radical difference between the natural and social sciences as far as technology is concerned. There is really no comparable 'technology of the social sciences' that can match natural science's interventionist capabilities.

Science as Political

The multi-facetedness of science is not limited to how it creates its knowledge or how it uses that knowledge to control and fashion the world around us. Science is also inherently social in character. The origin of science is as much a product of creating a social community of scientists as it is a product created by individual scientists. This is one of the reasons why science is inherently political, if by political we mean decisions and actions that have to do with a group of people.

There are clear indications about the political nature of science. First is its relationship with the nation-state. All countries, in the name of development or because of their defence interests, have very close ties with the scientific community in that country. Scientists have often been at the forefront of war efforts and are the foundation on which any nation's defence research rests upon. They are also integral to a country's plans for development – whether it be in the fields of agriculture or IT or in building dams. This is also a primary reason as to why governments have been the largest spenders on science teaching and research all over the world.

Science is also closely tied to democracy but this relationship is a complex one. On the one hand, science as a practice is inherently democratic in that the members of the community of science are far more open to the pressures of social democracy. But then this is moderated by the demands of individual 'merit'. Various technologies have made democracy more vibrant but at the same time government crackdown on democracy also are made possible by various intrusive technologies. Confronted by this constant ambiguity, scientists often tend to claim that science is completely neutral with regard to politics and social pressures. Scientists claim that politicians use science in a manner which a scientist may have no control over. The common description is that a scientist only develops an idea or technology but the use of it really lies in the hand of the politician or policy maker. They tend to extend this idea to suggest that they (the scientists) are not responsible for what is done with that technology (such as the nuclear bomb) since their task is only to build the technology and the responsibility for using it lies in the hands of the politician. Such a simple distinction between the scientist and the politician is not possible in modern times for science is inherently tied in with the political class. Very good examples of this constant engagement are the scientists' involvement with the Nazi as well as the Stalinist regimes. But like all communities there are very different political affiliations among the scientists. Interestingly, the communist movement has often had, at least in the earlier era in India, prominent scientists associated with them. One of the reasons for this affiliation among the communists and scientists was a common suspicion (if not outright rejection) of religion. Since science needs an enormous amount of expenditure it is often only the government which can handle that burden. This makes the government a patron of the sciences and this in turn leads to an uneasy relation between the politicians and scientists. But entirely because of this ambiguous relation, the very activity of science has strategies of political action inbuilt within it. This is seen very clearly in the rhetoric of science, in their attempt to influence public opinion through various methods in the popular media as well as institutional attempts to encourage students to do science, to work closely with the government on its defence projects and so on.

So, as we can see, both in the technical definition of science as well as in the public understanding of it, there is much ambiguity about what really constitutes science. When a community of scientists attempt to define science, they emphasize ideas of method, evidence and truth. When individual scientists write their personal impressions of science, they invoke ideas of wonder, awe, beauty and curiosity. When non-scientists write about science, most often they are more cautious in their appraisal although certain beliefs about

science are entrenched in the public imagination. For example, the beliefs that science is about truth, reason and rationality, that science is hard to do, that it needs 'superior' intelligence to do science are often strong beliefs of a society which are sustained through the public presentation of science, both by scientists and non-scientists.

References and Further Reading

Many websites have information on the science academies and their definitions of science. For example, see:
http://www.aps.org/policy/statements/99_6.cfm
http://www.sciencecouncil.org/DefiningScience.php
http://www.vigyanprasar.gov.in/scientists/cvraman/Raman1.htm
http://www.unf.edu/coehs/resources/inquiry/what.html
http://www.science-house.org/CBLable/inquiry.html

Yeo, Richard. 2003. Defining Science: William Whewell, Natural Knowledge and Public Debate in Early Victorian Britain. Cambridge: Cambridge University Press.
Feynman, R.1968. " What is Science?" *The Physics Teacher* Vol. 7 (6).
Mayr, Ernst. 2004. *What Makes Biology Unique?* Cambridge University Press.
Shrake, D et al. 2006. "What is Science?" *Ohio Journal of Science* 106 (4).
For further reading on scientific method, see:
Gower, Barry. 1997. *Scientific Method: An Historical and Philosophical Introduction.* London: Routledge.
Hacking, Ian. 1983. *Representing and Intervening.* New York: Cambridge University Press.
A seminal work in the history of science is:
Kuhn, Thomas. 1962. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

II

Doing Science

It is often said that science is what scientists do. But what is that scientists do?

Being Scientists

Scientists go to office just like countless others. They have various tasks in their offices. They teach (if there are students), they write (when they are writing papers), they do administrative tasks, they look after various chores in the department and in the organization. They also spend appreciable amount of time talking to colleagues, students and others. (And these days they spend an inordinate amount of time on the net.) They spend a good deal of time drinking coffee and tea. Part of the folklore of scientific activity is about doing science in these tea breaks. There are numerous anecdotes about how great ideas emerged during these informal tea meetings. In fact, many research institutions have writing boards in informal coffee places just in case an idea strikes a scientist or a discussion begins during these moments. Science is also full of anecdotes about how new ideas emerge while not engaged in the act of thinking science, like when walking and even dreaming.

What else do scientists do? To indulge in some stereotyping: they argue endlessly, they often question what others take for granted, they can be polemical, they have great confidence in what they do and what science is like, they are also, quite often, very much conversant with the activities of the rest of the world. They are quite opinionated

about politics and society. Many of them also have an interest in the arts. Doing science, for many of these scientists, is not only about certain problems in science or teaching certain disciplines of science. It is to have a particular way of looking and responding to the world – both the natural and the social world.

Scientists, contrary to popular myths about them, are not always sterile, logical beings. They lose their temper quite easily – perhaps this is their way of exemplifying this curious phrase, which is special to the Indian constitution, called 'scientific temper'! Their disagreements among themselves and in meetings are rarely about science but about personalities. Good scientists often have strong personalities with clear views on what they like and dislike. The fights over grants and getting access to resources are legendary in the field of science. Quarrels over priority in research, taking control over laboratories and programs are endemic to science all over the world. Bitter feelings about science organizations like the science academies, politics over who is chosen into these academies as well as politics over prizes are also very common.

In other words, science is not a homogenous community just like it is not a homogenous set of disciplines or a homogenous method. Scientists and students of science are well aware of a strongly entrenched hierarchy in science. In the classical tradition of science, theoretical physics had greater prestige and merit as compared to other sciences, including chemistry and biology. Within the sciences, there is often a well established intellectual hierarchy between theory and experimental science. Within theory, there is again an accepted distinction between the merits (or meritoriousness) of those who do fundamental theory (like quantum theory or particle physics) as against those who do 'phenomenological' theory (typically like those working in solid state physics and other fields). Such a hierarchy influences the choices of the 'best' students who often take up research positions based on this hierarchy. Within departments, the conflict between theoreticians and experimentalists survives even today in almost all disciplines of science.

The lack of a homogenous community is also found in the opinions scientists have of science disciplines other than theirs. A well known example is the set of typical beliefs held by physicists about chemistry. An extreme example was exemplified during the debate following the 'discovery' of cold fusion. Cold fusion was 'discovered' by the chemists, Pons and Fleischman, and the fact that they were chemists was reason enough for this discovery to be dismissed by many physicists (Collins & Pinch 1993).

Yet another well known hierarchy is between sciences and engineering. Often this is captured under the distinction between pure and applied science, with 'pure' science seen to be intellectually superior to 'applied' science. In terms of actual practice, one can see the effects of this hierarchy in institutes which have both science and engineering departments. Both scientists and engineers think of themselves as different tribes or communities with little in common. They interact very rarely and do not in general attend seminars in their respective departments. They differ drastically on the methods and aims of science as a day-to-day practice. Commentators on Indian scientific institutions often point to this dismissive view towards engineering as the reason for the lack of world class engineering departments in India. The 'best' students in a research institution often tend to move into theoretical work at the expense of both experimental and engineering fields.

The dispute between scientists belonging to different disciplines is partly catalysed by over-specialization, a characteristic endemic to all sciences. Often, within a same department, one would find scientists who do not understand their colleagues. For example, in a physics department seminar on particle physics, colleagues working in experimental physics most often will not attend. Specialization also implies that science has fissured into innumerable specializations so much so that a sub-discipline (say organic chemistry) will have many sub-specialities. Given that the value of science rests upon the importance of newness and originality, and there is a strong reward system for discoveries and inventions, there is indeed a tendency

among scientists to fight over these resources, awards and so on, particularly because in their view the value of these awards and grants often privilege one kind of science over another.

Much of this behaviour of scientists reflects an essential nature of science, that of competition. The narratives of science, which create a public image for science and influences students who enter into science, quite often stress, explicitly or implicitly, the notion of competition. The first lessons in science begin with the idea of problem solving. Exams designed to test science often privilege speed in solving problems. In the activity of science, this common maxim is indeed true: nobody remembers who comes second in a race. The competitive nature of science translates into the competitive nature of the whole educational system. Competition is also encouraged by the act of giving financial and other awards. Moreover, in the very idea of originality there is an element of human desire to be acknowledged as the leader, as being unique. In fact, the other important character of science – its strong stand against copying and plagiarism, and thus its support to establishing structures of copyright – is primarily to protect the holy grail of science, namely, originality.

What is it then that holds all these diverse, often incommunicable, disciplines together under one common rubric called 'science'? In reality, it is only the accident of belonging to the same institution that is common to all these scientists in different disciplines. However, although scientists within that community will differ on the scientific merit of physics versus chemistry or pure versus applied science, they still come together as a community when challenged from the 'outside'. Arguably the most important marker of science is this capacity to build institutions at all levels of the society. Science is primarily an activity of establishing community, solidarity and building institutions. These institutions range from departments in universities, Chairs in different disciplines, creation of new research institutes, establishing science and engineering academies with rules for electing members, various tiers of awards given to encourage science which starts from scholarships, prizes for best thesis, young

scientist award, awards for persons in various age groups, lifetime awards and so on. Along with these national award schemes, there are big international awards in all the disciplines of science. Today, in the name of promoting the study of science among students, there are scholarships to promote the study of science right from high school. The national talent exams in the sciences are part of every country's attempt to valorise the activity of doing science. All these point to one essential aspect of science – its inherent relation to various forms of institutionalization. Through these innumerable social institutions, science derives social legitimacy.

For good or bad, scientists are as human as non-scientists. There is much written on the nature and psychology of scientists. As mentioned in the last chapter, scientists are often portrayed like children. They show innate curiosity, they exhibit awe and wonder at the workings of nature. They question like children and like children they do things oblivious to whether what they do is good or not. In general, many of these characteristics are indeed true of many good scientists, if not all. Scientists do, in general, show a greater degree of scepticism and doubt, and question many received ideas. However, they also exhibit some striking human tendencies of the non-scientists. They believe in a wide variety of beliefs which have nothing to do with science and which are sometimes contrary to science. Many scientists are religious and believe in God. Many scientists go to astrologers. They have their own types of superstition. They participate in many social practices which could be called as irrational by some. Many of them also support regressive social structures. In their personal lives, they are often emotional and intemperate when it comes to personal conflicts and problems. They are, like other professionals, able to distinguish between what they do as a career and what they do as an individual. They often recognize that being scientific (if this means being logical or rational) is often applicable only to specific scientific problems they are dealing with and not to personal interactions or social structures.

So this is what scientists do but perhaps science is not merely what scientists do: it is what they do when they do science. So what do scientists do when they do science?

Doing Science

Typically, the activity of doing science involves two separate activities – theory and experiment. As I mentioned earlier, most often these are two completely different activities although theorists are aware of experimental results and experimentalists are aware of theoretical results. Both these communities know of each other's work in a general sense and not the nitty-gritty details. There is also a third community in science, one that is not often called about. This is the community of instrumentalists comprising of technicians and engineers, who are most often subsumed under the community of experimenters (Galison 1997). To understand what scientists do, it is necessary to explore the nature of doing theory and doing experiment.

Doing theory

What do theorists do as theorists?

First of all, when students learn theories of science such as the theory of gravitation, theory of chemical reactions or theory of evolution, they learn them as a complete and coherent set of arguments. What they learn is the final product and therefore they often do not get a glimpse of the process that leads to theory formation. Theories take years to build; some theories get refined over centuries! In the day-to-day activity of theorizing, very rarely do scientists construct full theories. What they most often do is to build a theory step by small step. What we see as the final theory is most often built on many small theories. There are also many theoretical attempts that are discarded along the way.

The first principle in doing every-day theory is to deal with small problems, not big ones. What this means is that a physicist, for example, will not start by trying to solve the problem of gravity

or a biologist the problem of life. Instead, she might begin with a small problem, which could be in the formulation of a problem, trying out new assumptions, using a different model or finding new parameters for calculation. To draw upon an analogy from history, one could call these small efforts the 'subaltern theories', theories which are below the surface and are often ignored in the large theory. In their everyday activity, theorists most often are involved with such subaltern theories.

There are various levels in constructing a theory. Firstly, a problem is identified – this problem is often chosen because the community of scientists in that particularly area believe that it is a problem. The problem is then situated within a particular description or a particular model. Many times the problem might be nothing more than finding a way to solve an equation in the model or changing the assumptions and parameters of another model. When a theorist solves an equation, for example, one part of the puzzle is solved. A paper recording this solution is then written. If it gets published, it becomes a part of scientific literature. Now this result is open to other scientists to critique, modify, expand and accept.

There is often a creative and intuitive element in choosing a theoretical problem. But it is also equally true that the problems which are deemed to be worthy of solving are suggested by others. When a student is working for a doctorate degree, the guide most often suggests the problem and the student then attempts to find ways to solve it. For the majority of scientists, the scientific community articulates the problems that are then collectively taken up. So what is seen as an interesting problem is often what the community of scientists in that area see a problem worth solving. Very rarely do scientists engage in completely new problems or create new perspectives which others haven't done before them. Where scientists succeed in propounding new ideas, they become the leaders of a field. But such moments in theories are few are far between and are not part of everyday work of scientists.

Before we go further it might be useful to briefly consider the

question 'what exactly is a theory?' When does a scientist know that she has formed a theory? What is the relationship between having a new idea and an already existing theory?

While I will discuss the nature of theory in greater detail later, it is worthwhile to briefly summarize the salient points of a theory. A theory is primarily a narrative, the particular way in which a story is told. We can look upon the 'small' theories and the 'subaltern' theories as short stories. A big theory, like a 'final' theory, is akin to a novel where many shorter events are put together in a coherent manner. Just like a story has character, a theory too has its own character –objects which figure in it, concepts that are used and so on. Just like there are events in a novel, so too are there events which are described in a theory.

A narrative is composed of other elements: descriptions, explanations and models. A theory primarily begins with a description of some phenomena or event. Very rarely is this description literal: that is, the description of natural phenomenon is primarily a model of the phenomenon. The idea that scientific description is a special kind of description can be traced back to Galileo. Galileo is called the father of modern science not only because of his contribution to the study of motion but also because of his views on what it is to do science. There are two aspects of Galileo's approach that were very influential in the development of science. Galileo was a true scientist in that he was both a theorist and an experimenter. He was among the first to integrate the theoretical and experimental approach as the mark of scientific activity. The second major insight of Galileo was to define scientific description as one which is based only on measurable concepts. Galileo's emphasis on mathematics as being essential to science arises from his view that the mathematical was the measurable.

Galileo understood well that a phenomenon could be described in various ways. But for a description to be scientific, he argued that only measurable concepts should be used. For example, one can describe a falling stone in many different ways. We could talk about

the sound it makes as it moves through the air, the feeling of hardness of the stone or perhaps the changing colours of the stone as it falls. For Galileo, such descriptions are not scientific since they are not based on concepts which are quantifiable and measurable. So in the case of the falling stone, he used height and time as two measurable concepts. He described the falling stone by noting the height through which it fell and the time it took to fall. Both these are quantifiable. From these observations he found the relation between height fallen and the time taken.

Such a description is a particular kind of description and the challenge of science is to discover new kinds of measurable concepts in order to give richer and thicker descriptions of phenomena. For example, a falling stone has a velocity, which is also quantifiable. However, Galileo realized that using only height, time and velocity was not enough to fully describe the phenomenon. So he also used the concept of acceleration, which is also quantifiable. It is indeed remarkable that with the basic concept of length, time, velocity and acceleration most of the 'science' of motion can be described. If we add the other measurable quantity, mass, then we have all the tools necessary for classical physics.

The interesting thing about this is that you do not need anything more than these measurable concepts. Physics of motion does not need the concept of colour or taste or smell. Philosophers considered these properties as secondary properties – properties of the human who perceives the object and not the properties of the object or event per se. In removing secondary qualities from physics, Galileo was removing the role of the human in the sciences. This suspicion towards these qualities are so ingrained in science that even a discipline like chemistry, which is a discipline filled with colour and smell, ignores these secondary qualities in its scientific descriptions! In the science of chemicals, these qualities are never part of any significant theory (although this is a view that has been challenged in recent times).

So along with the amalgamation of theory and experiment, Galileo's claim that quantifiable descriptions are essential to

science profoundly influenced the understanding of what science is. Being quantifiable means expressible as number or functions. Thus, what Galileo was pointing to was that scientific descriptions should in essence be mathematical descriptions. Now, we can ask, what is so special to mathematics that it is necessary for scientific descriptions? Galileo found a wonderful (but very troubling!) answer by claiming that the 'Book of Nature' was written in the language of mathematics. Thus, what he was suggesting is that if one wanted to best describe nature we have to use the language of nature itself – namely, mathematics. (I will discuss the larger implications of this view later on in the book.)

I had earlier noted that modelling was an integral part of everyday science. Scientists spend an inordinate amount of time playing around with models and not with the phenomena of the world. This activity of modelling has a long history and an influential figure in this revolution was Sir Issac Newton. Newton's book 'Principia Mathematica' is a compendium of the most original ideas that gave rise to classical physics. In this work, he was concerned with understanding the nature of motions. Much before Newton, the idea that motion is relative was well known. But the question was whether it was possible to distinguish real and apparent states of rest and motion. For Newton, his work was primarily a way to help us understand what 'true motion' is. Any theory of motion should be able to not only describe motion such as a falling stone but also the motion of the planets. While we can drop a stone and watch it fall, we cannot 'see' the movements of the planets. We only infer their motions.

Newton introduces the idea of modelling – of describing phenomena not exactly as they are but in terms of simplified pictures. Thus, we can talk of the motion around the sun by picturing the sun as a dot and the earth as another dot circling around the sun. In this model, the size and shape of the sun, the colour, heat and 'smell' of the sun are ignored. Instead, the massive sun and earth become points. Thus, the physics of motion becomes a problem of geometry.

The basic assumption here is that a model mimics certain features of the phenomenon and the model is 'as if' the phenomenon is like it. This 'as if' feature of models has been the defining characteristic of theories after Newton.

Not just physics, even chemistry is full of models. The atom is described analogously as a solar system with the nucleus (sun) at the centre and electrons (planets) revolving around it. Atoms are themselves modelled like small spheres. Molecules are shown as small balls attached with rods. The rods are the pictures of bonds that hold the atoms together. The model of a gas is that of molecules as small balls which bounce off each other. This is the billiard-ball model based on the analogy with the game of billiards. States of matter like solid or liquid are also modelled on similar lines. Across all levels of science, including biology, we see such simplified pictures of the more complex reality of nature. The famous gas laws, such as Boyle's law, are called as ideal gas laws because they describe a gas as a collection of smooth round balls moving in a container. Science creates a picture of the world and this picture is not exactly like the world is but is merely a caricature, a cartoon. Atoms are not like how they are often pictured, bonds are not like rigid rods, molecules are not smooth round balls, but somehow this 'as if' description seems to work. This 'as if' description is necessary for science and is at the foundation of scientific theories.

When a theorist is doing theory, she is very often creating, manipulating or deriving consequences of a model. This is the day-to-day work of a theorist. When new models are created or changes made to existing models, the scientist brings these to the attention of the scientific community, leading perhaps to publication. One must remember that many such efforts also do not get published for a variety of reasons.

There is much in this activity which is like a game. Doing theory is indeed very much like playing a game. Building models is a game in the sense that one tinkers with various 'objects' and 'rules' to see what one gets. The game which scientists play also has

a set of rules – these rules are often the 'rules' accepted in a theory. The scientist then plays around with the model – she will change an assumption or modify a parameter or introduce a new term and then explore the consequences of such change. This exploration could be through mathematical calculations or computer simulations. Theory is imbued with this playful character. While indulging in this game, the scientist is not concerned about truth or whether this game describes the world correctly. These checks and balances come later, much later.

There are some other elements of doing theory. Earlier, I had mentioned Galileo's influential view that the language of science is mathematics. What distinguishes scientific description is the use of mathematics as against 'natural languages' like English or Hindi. Even where mathematics is not used, there is a modification of the way a language like English is used in the sciences. Scientific writing consists of different symbolic systems – a scientific text is a mix of different sign systems like natural language (say English), alphabetic symbols, graphs, diagrams, figures, mathematical symbols and so on. A scientific text is what is called a multi-semiotic text. Scientific theory is really a creative mix of different 'languages' and that is the power of theory in science. This interesting way of mixing semiotic systems influences the day-to-day activity of doing theory (Sarukkai 2002).

Mathematics is often an integral part of these models, although models in principle can be independent of mathematics. And even pure mathematics embodies much of the playful character that is so much a part of theorizing. The world for mathematicians is the one filled with ideal, mathematical objects and not the real objects in our physical world. Their playground has these non-physical objects like numbers, sets, functions, groups and so on. Like in all games, there are rules for playing with these objects. It should therefore not be a surprise when mathematicians like G.H. Hardy or philosophers like Wittgenstein claim that mathematics is another game like chess.

There are two pragmatic uses of mathematics in doing 'everyday' science. One is using known mathematical objects and results in the models which scientists create. And once this is done, the major problem for the scientist is to solve the mathematical problems that arise in the context of these models. In doing this, they also tinker with the mathematics to suit their ends.

The other important activity is to calculate and compute. This activity is essential to science because it helps the scientists to eventually relate the model to the world. A striking example is Einstein's general theory of relativity. At the end of some complicated mathematics, we have a simple, computed result that light will bend by some specific angle due to spacetime curvature. This result which is about a phenomenon in the world brings the theory back to the world. Most often, this is accomplished through the activities of calculation and computation, because these relate to what is ultimately measured. So we can see that what is special to scientific description is not merely using mathematics but using it to derive measurable quantities at the end.

This result oriented emphasis in all theories is what makes theories more than a story. In principle, for science, a theory is always under doubt and always opens to testing. So, although a theory is a narrative, a particular story, the demand placed on theory to match with observations makes it somewhat different from 'pure' fiction.

However, in everyday science, a scientist does not keep inventing new theories or even testing them. While it is easy it test simple theories, most other consequences of theories are extremely difficult to test. It may take years or decades before experimentalists build a proper experiment to test the conclusions of a theory. In fact, if the theorists wait for experimental proof before they continue their theoretical work, then very little work will be done! Instead, the theorists merrily continue to create their stories, their theories. If down the line their theories match some experiment, well and good; otherwise, too bad! It is essential for science that theories should continue to be developed without waiting for experiments to catch up. Scientific literature is filled, literally, with thousands of models,

problems and theories. The well-known example of string theory illustrates this tendency to create enormous theoretical literature without worrying about the experimental tests of these theories.

Doing Experiment

What do experimenters do in their everyday work? The paradigm of experiments must be the test tube experiments in schools, where students mix chemicals and record the consequences. Experiments in optics or electricity and magnetism are also familiar to students.

A scientist, in her everyday work, rarely does experiments like these. Experiments nowadays are so technical and sophisticated that an experimenter is much more like an engineer. The kind of experimental apparatus and the types of measurements made by the scientist have become very sophisticated. An experimental apparatus may occupy a table or a whole building (for example, particle accelerators)! Observations are an integral part of the experiment. Today, most often observation consists in looking at computer monitors! Experimental apparatuses are often engineered to high degree of precision. These are often built by specialized engineering companies.

Just as a theorist chooses a particular problem to work on, so does an experimentalist choose a particular experimental theme. The choice may be dictated by interest, topicality, availability of equipments and funds, and so on. It is quite rare for an experimenter to create an entirely new experiment. But when she does so, she would begin by designing an experiment.

Designing experiments, although not usually a part of everyday science, is an art. Experimental science has gone far beyond the early experiments of Galileo who (apparently) rolled objects down an inclined plane. In order to get accurate measurements, many innovations in design, observation and measurements have been introduced.

Experiments do a variety of things: verify measurements done earlier; try to duplicate results discovered by other scientists; refine experimental results already discovered – like refining the measurement of mass and charge; attempt to discover new phenomena, entities and relations; test whether the predictions of a theory are true; attempt to create new things like new chemicals and new materials. An experimenter in doing everyday science might be doing any one of these activities. The design of an experiment thus obviously depends upon what the experiment is meant to do.

There is a common perception that experiments verify theories. This is indeed an important aim of experimentation. But to actually do an experiment to verify a theory is an extremely challenging task. Very often, theories derive consequences without worrying how they can ever be tested. Consider the famous example of testing Einstein's general theory of relativity. This test was of measuring the bending of light rays when a light from a star passed a heavy object like the sun. The theory seems 'simple' enough but how does an experimenter even think of measuring how much light rays bend when they pass by the sun? This experiment required great ingenuity, as well as the occurrence of an eclipse. And it is not as if one goes and takes a photograph of the bending of light rays. The story of this experimental 'proof' is complex and the debate on whether the first experiment really proved Einstein's theory or not continues even today (Collins & Pinch 1993).

It is also rarely the case that a single experiment proves a theory. A simple idea does not imply a simple experiment. Even after experiments have been designed, it is not a routine matter to perform these experiments. Any student of physics working in a college laboratory will attest to be difficulty of finding the right values expected in an experiment. For example, the Michelson-Morley experiment is a neat and simple experiment which is performed in college laboratories. Here, even after the experimental setup has been given, and only measurements have to be made, it is quite often difficult to get the desired results. The slightest jar on the table or a microscopic misalignment of the mirror can completely throw the experiment off its track. Performing experiments is therefore a

laborious task, one that needs great skill, patience and perseverance. So also for experiments in chemistry and biology.

Once a scientist has her apparatus designed and built, she can actually begin to perform the experiment. Results will not be immediately obtained, especially if it is an original experiment. The scientist has to spend days and months tinkering with the set up and trying to make it work perfectly.

Observation and measurements are two crucial aspects of experimentation. While an inordinate amount of time may be spent on building the apparatus and making it work, the real test of an experiment is in the observation of the result and generation of data. In most cases, the experiment will have a long running time but the observation of the results will be only for a short time (Hacking 1983).

What does a scientist observe in an experiment? In today's highly specialized science, very rarely do scientists see a new phenomenon or new results. The observations are more often than not some reading of an instrument. Some experiments take a long time to design and build; although the 'running' of the experiment will many times be for a short duration. It also needs great skill to make sense of this experimental output and here theories are often helpful. Rarely do scientists actually 'see' the results of the experiment. They have to infer the results from instrumental observations. Everyday experimentation is all about patience, sitting in front of the apparatus, making sure that everything is running smoothly, and learning to wait! Later, in this book, I will discuss the nature of instrumental perception.

Publishing

Getting published is integral to the activity of science. It is one of the defining characters of science as an institution. The network of publishing sustains science as a social activity today. Recognition and prizes, including the Nobel, are awarded based on published work. There is indeed immense pressure on a research scientist to publish so

much so that it has led to an ironical motto in academic institutions: Publish or Perish.

What does a scientist do when she has solved a problem, derived a new result or made some new observations? Typically, if she is in an academic institution, she will write her result in the form of a research paper. This paper is sent out to a journal specialising in her subject. The editor of the journal will send the paper for peer review, meaning that it is sent to other competent scientists who can evaluate the paper and recommend its publication or rejection. Based on various parameters, which differ from one journal to another, the reviewers suggest acceptance or rejection of the paper. They could also, as is often the case, ask for modifications and clarification in the paper. It is not necessarily the case that the 'best' papers get published in the best journals. Each journal, in general, has a focus on certain themes and a different yardstick for deciding which paper is publishable.

Science as a profession depends entirely on these publications. A researcher's position in the scientific community depends on these publications. Given the inherent competitive nature of science, it should not surprise us to find that there is a competitive hierarchy in these journals. Some journals like Nature and Science are at the top of the heap and getting published in journals like these is supposed to be prestigious. There is a strong reward system inbuilt into this mechanism of publishing. Awards and promotions are based on the quality and quantity of publications. There are scores of journals catering to each sub-discipline.

A research paper is supposed to report some new result. Now, it is indeed difficult to recognize what is new or how valuable the new ideas are. If a journal insists on publishing only radically new results, then most journals would fold up. There is a gradation in the kind of new results that are reported. In theoretical work, most of the papers make small changes to existing models, discover new equations and solutions to them, suggest some relation between their model and some experimental results and so on. Experimental papers primarily report the results of the experiment.

The professionalization of publishing industry in science leads to an interesting paradox. There are literally thousands of papers published every month in journals across the world. In physics alone, there are over 1,100 journals listed, covering different sub-disciplines. Some of these journals publish weekly and we can now imagine the staggering amount of new, 'original' work published every week in all of science! Since these research papers are products of new contributions, one should ask whether so much new knowledge is really being created – that too every week.

Not really. A majority of the published papers are never referred to by other researchers. In fact, the importance of a paper is measured by the number of citation the paper receives in other published papers. So a given paper has a citation index and journals themselves are ranked according to indices such as 'impact factor'. The higher the impact factor, the more important a journal is. A paper published in a higher impact journal is seen to have more scientific merit. Citation index and impact factors are ways by which the scientific community tries to rate the quality of a paper since they recognize the enormous output among the scientists.

In response to the criticism about needless publishing, scientists often point out that science is a collective activity and the task of each scientist is to add her little bit to the grand project called science. This image is also part of the global aspirations of science. While it is relatively easy to distinguish really path-breaking work, it is far more difficult to assess the relative merits of research work done in everyday science.

A far more troubling question, one that has been raised by proponents of open access these days, is this: Who are the Publishers of these scientific journals? Almost all the big publishers are private organizations. They are also profit-making organizations. Therefore, journals in science are extremely expensive. Almost all the major journals are published in the West. Since they are priced in dollars, pound or Euros, the cost of journals becomes prohibitive for the rest of the world.

As a measure of the cost of these journals, consider the expenditure on journals by libraries in India. Most good libraries in India spend the majority of their budget on journals, sometimes to the extent of 70 to 80%. There are other problems with these international journals. The copyright in general rests with the journals and not with the authors. An author cannot put her paper in the net because of copyright issues. Consider the irony of the situation: scientists work hard to produce quality papers, a journal decides to publish them, the scientist gets no monetary remuneration for these papers and the private publishers are the one who make money in this process. Moreover, the results of the paper are not available in the public domain although in most cases the research might have been funded by government, and therefore public, funds.

Given this troublesome commercial element, many scientists have now begun to question this model of publication. The move to open-access publishing is becoming popular although not in countries like India where the prestige of publishing in 'foreign' journals is still unreasonably high.

The other aspect of the sociology of publication has to do with the asymmetry in the number of papers published by scientists working in countries such as US, UK, France and Germany. In recent times, there has been a growing number of publications from China, Japan, Korea and other smaller nations. However, a significant percentage of high impact papers come from people who are from US, UK and some countries in Europe. Papers from most of the other nations, with exceptions such as China and Japan, are an insignificant percentage of the total. The citation index of most of these papers are almost nil, suggesting that nobody in the larger scientific world bothers to even read these publications from the 'other' nations, including India.

What does this tell us? That only scientists in these few countries have the capacity to create new knowledge? Given the abysmal record of publication among Indian scientists, does this mean that Indian scientists are not as 'good' in science or not as creative? Does the lack of significant contribution from the Indian science community point

to some inherent problem either with Indian scientists or the Indian science institutions? In the Indian case, there is an added intriguing fact that seminal scientific ideas from Indian scientists such as Raman, S. N. Bose and J. C. Bose, to name a few, came in pre-independence times. Post-independence, although the amount of funding and support for science has increased dramatically, the quality of new work has decreased in terms of percentage contribution.

Answers to these question lead to a potential mine field! Let me discuss only one possible reason for this disparity: getting published and getting recognized are not merely reflective of quality alone. As commonly happens, an idea becomes prominent only when other scientists in well-known institutions decide to work on that idea and develop it. Almost always, the leaders of science supply these ideas and the army of scientists develop on them. Which idea a scientist decides to invest her energy upon depends on who the author is or the institutional address of the author. Of course, when the idea is radically new it might attract a larger number of scientists independent of who the author is but these cases are very rare.

Herein lies the paradox of publication. Most theories in science are ones that are developed in bits and pieces by a large community of science. This community building of an idea into a theory demands that the idea be first taken up by others. Here is where a lot of good ideas by scientists from countries like India lose out, since other scientists do not think it worthwhile to invest in ideas 'coming' from places like India. This is also one of the reasons why Indian science's contribution is so poor, both in the number of papers as well as the impact factor. Although there are exceptions and many influential Indian scientists are present, the overall impact of the scientific community in India has been disappointing, both within the country and outside it.

One reason is that there indeed seems to be a lack of confidence among Indian scientists. Brave new ideas are few and far between. There is too much derivative research done by Indian scientists. This is partly because these scientists still depend on the West to validate

their work. This leads to a piquant situation – good Indian scientists, in general, refuse to publish in Indian journals. Since the politics of publication is such that Indian journals have a low impact factor, the scientists rightly refuse to publish in them. The belief that validation from the West is more important also drives them to publish 'outside'. It is generally true that a paper by an Indian scientist which supports or builds upon work done by scientists abroad gets published more easily than work based on another Indian scientists' idea. Finally, it is also the case that India does not have significant numbers of research scientists in every sub-discipline. Universities in India have not produced uniformly good work and the Indian model of supporting research institutions has led to a situation where education has been decoupled from research and both these activities have suffered because of this.

All these reasons, and many more, contribute to the relative invisibility of Indian science in the global scenario. Some of it is surely linked to the politics of publication but the new movement towards open access in research has the potential to transform this. Ironically, although many countries in the West have taken proactive stance supporting open access, the Indian scientific community, as always, remains conservative about this move.

This structure of publication has serious implications for the country. Answers to questions such as what constitutes good science and what scientific questions are important are often dictated by the concerns of scientists outside India. This has lead to a complete polarization between the kinds of issues scientists work on and the problems facing the country as a whole. This does not mean that scientists should choose their research based on the presumed needs of their nation but in the Indian case the choice of research problems are often influenced by the decisions of scientists outside the country. This is ironic, since many of the seminal ideas from the West were developed when scientists in these countries chose to solve problems related to their social needs. The Indian scientific community has a problematical relation with Indian society and often explains its

alienation from the society by claiming that science is universal. Unfortunately, we rarely hear this argument from scientists from the US, Russia, UK or the European countries! Reflecting this troubling trend is the lack of scientific writing and publication in Indian languages. Although scientific publishing is largely moving to English language publication, some of the most important publications in the sciences and mathematics in the last century were published in German, French and Russian.

In the first two chapters I discussed some general themes in defining and understanding the nature of science and its practice. There is an image of science that is created in our contemporary societies. Both non-scientists and scientists buy into these stories of what science is as well as how scientists are. Popular descriptions of science and scientists in films and novels continue many of these stereotypes. Among strongly entrenched stereotypes are the following: science is logical and rational; science is only about truth and knowledge; science opens out a new world of reality; science is universal and is independent of cultures; human subjectivity has no place in science and thus human characteristics such as morality are not relevant in the claims of science. In the remaining part of the book, I will explore some of these claims in some detail.

References and Further Reading

Galison, Peter. 1997. *Image and Logic: A Material Culture of Microphysics.* Chicago: University of Chicago Press.

Sarukkai, Sundar. 2002. *Translating the World: Science and Language.* Lanham: University Press of America.

Hacking, Ian. 1983. *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science.* Cambridge: Cambridge University Press.

For more information about the fact that science is essentially a human enterprise like any other, see:

Collins, H., T. Pinch. 1993. *The Golem: What Everyone Should Know About Science.* Cambridge.

Eugene Garfield is acknowledged as the founder of scientometrics, the science of measuring science. This book published as a Festschrift for him has a range of articles about this field.

Eugene Garfield, B. Cronin & H. Atkins. 2000. *The Web of Knowledge: A Festschrift in Honor of Eugene Garfield.* Information Today Inc.

For analysis of Indian science, see:

Garg, K. C., B. Dutt and S. Kumar. 2006. "Scientometric profile of Indian Science as seen through Science Citation Index." *Annals of Library and Information Studies* 53.

Subbiah Arunachalam has written extensively on these aspects related to Indian Science. See the Wikipedia entry under his name.

III

Science and Logic

One of the most enduring images of science is its special relationship with logic and rationality. In fact, the logic associated with science is often seen to rub off on the scientists so much so that scientists are thought to be logical in all their thoughts and actions. We can see this pervasive relation between science and logic both within the community of science as well as in the public narratives of science. Historically too, science presented itself as a logical enterprise in contrast to religion which was supposedly infused with blind beliefs and superstition. Other activities such as art and literature too have been associated with the illogical and are often contrasted with the logicality of science.

The attraction of science, especially for children and young students, is very much catalyzed by the stories of discovery in science. Science texts are filled with anecdotes about how scientists discover new stars and galaxies, fundamental particles, new chemicals, viruses and so on. Even in the public domain, science is most powerfully communicated through hundreds of exciting stories about scientific discoveries.

Not so surprisingly, many of these stories in the public about the romance of creating new things in science often do not tell the full story of the discoveries and inventions. This is because the complete stories of these discoveries and inventions are not only complex but they – in many cases – do not illustrate the strict logicality associated with science.

Consider these examples (Gratzer 2004). Kekule's discovery of the structure of benzene molecule is well-known: he dreamt of atoms which were 'twining and twisting in snake-like motion' (in his words) and suddenly he saw that 'one of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes.' Kekule's discovery of such molecular structures revolutionised chemistry. Kekule's discovery was not a product of logically trying to discover what the structure of benzene could be. In the case of Kekule, the discovery was primarily a product of two instances of dreaming. A similar case of discovery through an act of dreaming happened in the case of Loewi whose work on the chemical transmission of the nerve impulse got him a Nobel Prize.

Similarly, X-rays were discovered by Rontgen entirely by accident when he was troubled by a source of faint light in his darkened laboratory. Becquerel discovered radioactivity by another accident of placing a crystal of uranium salt on top of a photographic plate along with a copper cross and putting all of them in a drawer. He was waiting for sunny weather but many cloudy days passed by. 'Tired of waiting' (in his words), he took out the plates – and thus accidentally discovered radioactivity when he found that the plate showed an image of the cross even though it was kept in darkness.

Different families of sweeteners were actually discovered through accidents: in one case, the researcher had spilled some chemical on his hand and when he had dinner he could detect a 'curious sweet taste' – this was the discovery of saccharine; another family of cyclamate sweeteners were discovered when a research student kept his cigarette on a bench and when he smoked it after picking it up he detected sweetness; sucralose was detected because one research student misheard his professor who asked the student to 'test' a chemical but the student misheard it as 'taste' it!

The synthetic discovery of indigo occurred when a worker was stirring a chemical with a thermometer and the thermometer accidentally broke. The mercury in the thermometer mixed with the chemical and a new compound was formed, thus leading to

the development of indigo. Many such discoveries were often catalyzed unsuspectingly by a variety of causes including careless cleaning of laboratory equipments. Fermi himself writes in a letter to Chandrasekhar about how against all reason he decided to use paraffin instead of lead and this led to the discovery of the effect of slow neutrons which catalysed the development of nuclear physics.

There are many such cases in biology ranging from discovery of enzyme action to chemical reactions in the nervous system. A well-known example is the discovery related to the beating of a heart in a solution. The lab assistant did not bother to place the heart in a distilled water solution and instead used tap water which led to sustained beating of the heart. On finding the composition of the tap water, the influence of calcium ions was discovered. Similarly, an important step in hormone research was accidently made possible because a janitor left the lights on during the nights in the laboratory where hypophysectomised birds were kept. Another intriguing discovery is the discovery of vitamin thiamine which was accidentally catalysed because a cook did not want to feed boiled rice to the chickens and instead fed them polished rice.

Nobel prizes have been given to many of these discoveries discovered in this manner. There are countless such stories, not only of major discoveries that led to the Nobel but also in the discovery and invention of many little ideas that are part of everyday science. How do we understand this character of scientific discoveries along with the claim that science is logical? If we claim that scientific ideas arise through a well-established logical method then we cannot explain many of the creative jumps which lead to new knowledge. One way to respond to this is to say that new discoveries are matters of creativity and scientific creativity is as ephemeral as artistic creativity. Reichenbach, a philosopher of science, suggested that in the case of science there are two different contexts: a context of discovery and a context of justification. While the context of discovery may often be inspired by such seemingly random, creative processes the context of justification (the way in which these discoveries are justified to the

larger scientific community) involves method and logic. Creativity in general is often accidental or at least not predictable and not trainable. But we should also recognize that although these discoveries are serendipitious they nevertheless involve some scientific competence in the discoverer.

To further understand this important theme of the relation between science and logic, it is necessary to understand what we mean by logic.

What is Logic?

We are endowed with sensory organs that allow us to experience the world. Our knowledge of the objects in the world is derived from these experiences. But quite mysteriously, we also seem to have knowledge of that of which we have no direct experience. For example, we are able to predict that it will rain by seeing dark clouds. This predictive knowledge does not come from experience because what we predict has not happened as yet. Also, from a few pieces of information we are able to know new information without being told about it. We seem to know – without any direct experience – that if an object is smaller than another then the second object is bigger than the first. We often derive knowledge through a process of reasoning.

It is this process of reasoning that is referred to as logic. Reasoning is a simple process of connecting two sentences together, two thoughts together, and then arriving at a conclusion. For example, suppose we have two sentences: 'This fruit is red' and 'All red fruits are sweet'. Given these two sentences, if we conclude that 'This fruit is not sweet', then we seem to be making a mistake. Given these two sentences, it seems to be the case that only one correct conclusion is possible for any of us. This is the statement that 'This fruit is sweet'. The process of inferring in this manner is referred to as deductive inference. There is a certainty to this process of reasoning. Another way of saying this is to say that from two true sentences you cannot *deduce* a false sentence. The inference we make in generalization

is most often *inductive* inference, where from a few samples we generalize to new situations.

Logic is a study of such inferences. It is an analysis of arguments of these kinds. Logic allows us to understand under what conditions such inferences are correct, what kinds of mistakes are possible in making these inferences and so on. The human mind is always in the process of making inferences. Three common kinds of inferences are the deductive, inductive and abductive. Often our actions are based on probabilistic inferences that we make. In this sense, being logical is a natural characteristic of being human. As Boole described it, logic is nothing but the 'laws of thought' – the way we think has a structure and this is logic. But if this is so, why are we 'illogical'? To understand this, we have to understand in what sense we are illogical, what kind of mistakes or fallacies we do when we reason. Some would say that there is a logic to illogicality too! This only means that there is a particular way of being illogical.

Consider some common examples of inference which we make in our daily lives. We see smoke over a particular place and we immediately think that there is fire there. Although we do not see the fire with our eyes we are able to infer that there is fire there – no wonder then that inference was equated with the capacity to 'see' through the mind's eye. That is, we come to know of something in the world through a capacity of the mind alone. This in a nutshell is the 'power' of logic and is the reason why logic has been privileged within science. Scientists recognize that our sensory organs are very limited; our senses also mislead us – tall trees look small from a distance, we see a mirage of water when there is really no water and so on. So although perception is our dominant mode of knowing the world, that kind of knowledge is doubtful. In contrast, some philosophers believed that knowledge acquired through the mind, through thinking and following the laws of thought was far more superior since there was certainty associated with it.

This certainty is what is so special to logic and influences the attempt over centuries to make knowledge as certain as that made

possible through the proper functioning of the laws of thought. But right from the beginning this certainty was only associated with one kind of inference we make, namely, deductive inference. This is the kind of inference we usually make when we make inferences based on categorization – for example, once we know that all red fruits are sweet then we can deduce that every red fruit will be sweet. This is knowledge through the act of thinking alone because even without tasting a red fruit we can infer that it will be sweet. So it is the case that we have knowledge of the world not just through our five physical senses but also through the use of the 'sense' of mind. The mind too functions, at least metaphorically, like an eye through which we derive truth and knowledge of the world.

But absolute certainty is not available in all inferences. Inductive inferences, where we generalize from a few cases to many or all, is one such example. An example from the Indian logical school, Nyāya, is illustrative: if we find that one grain of rice is cooked in a vessel then we infer that all the grains of rice are cooked. There is really no certainty in such an inference. It is possible that one of the grains may not be cooked when we check all the grains. Now, a very important part of logic has to do with probability and not with certainty. In particular, for science, it is these probabilistic logics that are useful.

Where is Logic to be Found in Science?

All that we can say from the examples of creativity in science is that scientific discovery is not outwardly 'logical' or based upon a particular method that will help the scientist to discover new ideas. This does not mean that the activity of science is not engaged with logic. The difference between discovering and justifying these creative insights is one that is based on ideas such as theory, relation between experiment and theory, justification of the experimental set up and so on. Such arguments are part of the structure of rationality of science. But one should not assume from this that science is always moderated by logic for it is not.

Part of the problem lies in how logic is understood. From the

ancient Greek tradition to modern logic, logic is presumed to have certain characteristics: it is universal, is not related to the empirical world and is different from empirical knowledge (or knowledge of the world). In contrast, science is fundamentally about the world, it is fundamentally a type of knowledge of our world. Therefore, in principle, science cannot be reduced or even equated with logic.

Another related problem is that there are many types of logic. Logic, like other disciplines, has developed extensively from ancient times. There are now new types of logic which are quite different conceptually from early Greek logic. Another example of a different kind of logic is 'Indian logic', which was the logic as described in ancient Indian philosophical traditions. Indian logic is a classic example of logic which is not based on presuppositions that logic is universal, not empirical and not epistemological. Whether it is the Nyāya school or the Buddhists or the Jainas, Indian logic is a rigorous analysis of inferences that we make. For long, because of this empirical and epistemological element explicitly present in Indian logic, many logicians claimed that Indians had no tradition of logic. Given the direction that modern logic has taken today this claim is not so forcefully articulated now. But more importantly, Indian logic shows how science moderates logic and not the other way. Many conceptual ideas that arise in Indian logic resonate strongly with scientific methodology and praxis. This does not in any way imply that Indian logic is 'doing' science. What it is doing, however, is expecting logic itself to be scientific, in contrast with the position that science be logical (Sarukkai 2005). I will discuss the nature of Indian logic later in this chapter.

Among all human activities, science is seen to be the exemplar of logical thought and analysis. This is mainly because the methodology and the results of science are related to ideas such as objectivity, truth, laws and rationality. Science is also explicitly connected with logic through its use of mathematics. In the development of modern logic, the association between mathematics and logic proved to be very important. On the one hand, the shift to symbolic logic meant that logic was being presented in a form similar to mathematics. On the other hand, the belief that mathematics can be entirely reduced to logic, meaning that all mathematical statements can be reduced to logical statements, brought mathematics and logic much closer. This belief called logicism, championed so bravely by Russell, was also based on the belief that mathematics is the exemplar of deductive logic.

It is commonly argued that Greek logic was modelled on mathematics. Although the mathematics in Greek times and in the times of Russell was vastly different, some basic beliefs about the nature of mathematics remained the same. Some of these continue to inform the image of mathematics. For example, mathematical truths, like $2 + 2 = 4$, are considered to be universal truths. They do not depend upon individual human perspectives or on specific material conditions, including dependence on space and time. They are understood to embody some fundamental, objective and universal structures, independent of the contingency of our existence. This also means that they are not empirically grounded, that is, their truths do not depend upon our observation, experiment or any other form of intervention in the world.

The relation of science with logic is also manifested in other ways. While the mathematical component of science is seen to reflect the deductive structure of argument in science, there is much in science which draws upon other forms of argumentation, particularly inductive and abductive inferences. Many of these inferences in science follow the same structure as the common inferences we make, such as the inference of fire from smoke. Thus, the philosophical issues that arise in analysing inferences in science share some common conceptual ground with 'ordinary' everyday inferences. Paradoxically, the strong empirical grounding of science places it in potential conflict with the Western tradition of formal logic. Science draws upon observations and reason, and by weaving them together constructs its narratives of the world.

Scientists do not do science by asking whether their thoughts

are 'logical'. In their practice and methodology, scientists indulge in activities which are many times merely habits and rituals. In fact, scientific knowledge, like other knowledge systems, has a strong ritual component to it. Being ritualistic is also to be methodological and one of the important characteristics of methodology is that it trains one to do something without much reflection on what they are doing. Scientific methodology shares this trait with various other human activities which are ritualistic in character even as it is distinct from them in other important ways. Habits, creative thinking, serendipity, 'irrational' action and such, are placed under the context of discovery. The step of justifying these discoveries and results, where the claims are placed within a larger community for acceptance, is a process that is outwardly not arbitrary, illogical or irrational. It is in this domain that logic makes an obvious entry.

Therefore, it is not surprising that the association of logic in science is primarily found in scientific methodology. After all, much of science is based on ways of thinking which are very similar to what we do in our ordinary lives. Scientists do not infer any differently from non-scientists, although they may subject their inferential conclusions to more rigorous and varied kinds of tests. In most part, what is different in scientific thinking is the kinds of things they think about, the tools they use to analyse, an undercurrent of scepticism in their thinking combined with a strong streak of pragmatism. But as far as being logical is concerned, the ways in which they are logical are very similar with the ways in which other humans are logical. This conclusion is almost tautological if we understand, as many do, that logic is about 'laws of human thought' as mentioned earlier.

However, the methodological instinct in science takes commonsense logic to a more refined level. Thus, it is no surprise that the relation between logic and science begins and ends with methodology. For example, Cohen and Nagel (1992) make explicit this connection by noting that in essence 'scientific method is simply the pursuit of truth as determined by logical considerations.' A common element in this method is the process of hypothesis

formation and it is no surprise that among the first elements of scientific methodology, the above authors mention the formulation of proper hypothesis. It is very possible that formulating a hypothesis, to explain a phenomenon, may well feature non-logical elements since sometimes hypotheses are mistakenly chosen. But, on the other hand, knowing how to frame an appropriate hypothesis is itself part of methodology. However, logic makes its proper appearance when deductive consequences of the hypothesis are explored. Thus, from some hypotheses we make on observing a phenomenon, we deduce possible consequences and if those consequences hold good then the hypothesis is probably right. This, in essence, is the hypothetico-deductive model that has been discussed in great detail in the philosophy of science.

Science, in a fundamental sense, can be understood as a discipline that constructs theories based on some observations and in so doing, uses certain logical processes. Theories describe, explain and predict. Framing hypotheses and deductively arguing for their consequences are also an integral part of theory-making. In general, the explicit role of logic is first manifested in the move from some observation to a theory about this observation. Logic is also manifested in the various logical relations between theories and observations. Many scientific statements, including scientific laws, are implications – as manifested in if-then statements. For example, one of Kepler's laws illustrates a deductive implication: 'If the attraction between two masses is inversely proportional to the square of the distance between them, and there is a sun with one ambient planet, then the orbits of the planet will be an ellipse with the sun in one focus.' Such implications are also found in statements related to definitions: 'If an animal has more than six legs then it is not an insect.' A large number of scientific descriptions are causal descriptions which also have this structure, as for example, 'If a piece of litmus is placed in acid then it will turn pink' (Trusted 1979).

Not only are such examples true of statements across different scientific disciplines, the logical structure is also true of the relation

between theories and experiments. If the theory-observation relation is logical, then it allows us to claim that if the theory is true then the appropriate observation entailed by the theory must also be true. An important principle of implication is that in a conditional of the form 'If p, then q', when p is true, q has to be true. So if we look upon theory as p and observation statements as q, then if p is true it implies that q has to be true. Such a logical relation also satisfies the other condition, namely, that if observations are true it does not imply the appropriate theory is true, following from the logical consequence that if q is true, it is not necessary that p must also be true. Moreover, according to a logical principle, if q is not true then p is also not true. In other words, if there is no observation then the theory is wrong. This, in essence, is the principle of falsification. So we can see that falsification has a logical basis.

Much of what I have said here refers to deductive logic. However, science is not possible without the extensive use of inductive inferences. Induction is a type of inference. Consider some common examples: a ball that is thrown up in the air falls down. We see this happening many times and in many places, and we generalize from particular observations to the general claim that whenever a ball is thrown up, it will fall down. This capacity to describe a particular behaviour of the ball in all cases, whether spread over space (wherever) or time (whenever), is a mysterious one. What allows us to talk about these cases with any measure of certainty? We also make inductive inferences when we draw conclusions about all members of a class from some observed members. For example, from tasting one drop of seawater we conclude that all drops of seawater will be salty. Although in normal usage we tend to use the word 'all', such generalizations are also expressible through statistical generalizations, such as saying that something is true 60% of the time. Such examples are called induction by enumeration. Analogy is another kind of induction where from observation of some property or properties in one object we infer similar properties in other objects.

We can distinguish between deduction and induction in this

manner: deduction is nonampliative inference and induction is ampliative inference. In ampliative inference the conclusion contains more than what is in the premises. The uncertainty in such inferences creates a potential conflict for science, and scientific methodology can be seen as a method to try and make such inferences as certain as possible. The approach to induction that is most commonly accepted today is the probabilistic approach, which has also become the backbone of scientific inference.

Are Other Activities Also Logical?

In the popular imagination not only is science essentially related to logic it is also that most of the other non-science activities are not logical. In public debates about science, scientists often claim an exclusive right over logic and rationality, and consider all other activities, including social science, as not being as logical as science. Given what we understand by logic, it is indeed difficult to see how only science is concerned with logic. Even theology sets out its claims and arguments in a logical manner. It finds ways to relate evidence to a larger theory of the divine. In the theological arguments of Indian philosophers like Sankara or Rāmānuja, any talk of the divine is presented through rigorous logical arguments. In fact, the language of logic and epistemology pervade these discourses. Similarly, one can see theology's engagement with logic in the writings of Augustine and Thomas Aquinas.

Logic pervades human action and human thought. Where science differs from other disciplines is in the set of conceptual terms that it uses. For example, science's idea of evidence is very different from evidence in theology and the major problem between science and religion often is about contrary views on the nature of evidence. Perhaps a more useful way is to look at the many components that go into science and see how logic is related to each of these components. Science is a discourse, is a narrative, is a method, is a practice, is a worldview. So there are many logics present in science: the logic of its discourse, the logic of its practice (that brings together

experiment and theory), the logic of its instrumental world, the logic of its method and so on. Once we break up the relation of science with logic in this manner then we can have a better means of comparing the rationality of science with the rationality of other human activities.

Cooking, sports, astrology, religion, literature all have their own logic in different ways and in different degrees. Fiction, for example, has a deep relation with logic; I will discuss one aspect of this relation in the next chapter. Cooking is a lot like chemistry and has within its practice elements of scientific methodology. Astrology makes stronger claims given that it has quite well-defined theories, claims to predict like science does, also uses calculations and so on. So to claim that these other activities are not logical like science is to misunderstand the role of logic in science as well as the importance of logic in other activities. One could perhaps go to the extent of saying that scientists intuitively understand the ambiguous relationship between logic and science – the best illustration for this claim is that logic as a subject is not taught to science students!

I would argue that science's scepticism, suspicion of authority, creative creation of concepts, the capacity to convert ideas into action as manifested in technology, are all far more important elements that should be used to distinguish science from other activities and disciplines. The reason why science is stuck on logic and rationality as distinguishing marks is more historical in nature and is part of the story of the origins of modern science where conflicts between science and religion were at the forefront. It is part of the larger movement in the western civilization, following Enlightenment, to appropriate reason and rationality as defining markers of their civilization. Reason and logic were used as political categories to distinguish and then subjugate cultures (note the often cited observation of the colonial British that Indians had no capacity for logic and reason) and when science continues this trend in response to other activities and disciplines even today we have to recognize the politics inherent in such an act.

So How Logical is Science? The Role of Beauty in Science

The other challenge to the belief that science is primarily logical comes from its own practice. First of all, the success of science cannot be explained if we look at science primarily as something logical. Science creates its concepts in ways that draw upon different types of intuition. For example, in physics some concepts are physically intuitive while some are mathematically intuitive.

Science cannot be reduced to logic. Even mathematics couldn't be although there is much more in mathematics which is purely about logic. Descartes could not create the physics that Newton did because he made one cardinal mistake: he thought that physics was reducible to mathematics and that it was a 'part' of mathematics. The fertility of the new science that followed from Newton was only because Newton could make physics more 'non-logical' than mathematics.

Let me illustrate this argument with another theme, that of aesthetics and the role it plays in scientific activity. In both theory and experiment aesthetic judgements (a judgement of what is beautiful, for instance) play an important role. Scientists routinely talk of some works of science as being beautiful. Many times aesthetic considerations play a significant role in the acceptance of certain theories. Scientists also place a premium on the relation between beauty and truth. Often, scientists choose theories as well as experiments which they think are beautiful.

We can find examples of this view across the different disciplines of science (Tauber 1996). Kohn points out that Darwin's theory of evolution had profound aesthetic influences. Darwin's 'aesthetic-emotional ambition', which was awakened on his *Beagle* voyage, was 'later transformed into high scientific theory'. Darwin's two influential metaphors of 'wedging' and 'entangled bank' were central to his *Origin of Species*. Kohn argues that the 'tension between the *sublime* and the *beautiful*' which 'later became *the* critical Darwinian theme' was reconciled in his two metaphors. In biology, the discipline of embryology illustrates a continuing aesthetic in its discourse. Gilbert

and Faber point out that the 'visual aesthetic of embryology puts a premium on emergent form and finds expression in its focus on symmetry, order, pattern repetition, and elegance (visual simplicity).' Another example is the 'aesthetic' analysis of an experiment on the replication of DNA by Meselson-Stahl which has been considered as one of the most 'beautiful' experiments in biology.

In the case of physics, Chevalley points out that Heisenberg believed that 'physics is like art.' Heisenberg argued that different conceptual systems in physics, namely, Newtonian, thermodynamics, relativity and quantum theory, are actually like different 'styles' of art. There is also a suggestion that the overthrow of Ptolemy's theory by the Copernican one was influenced by aesthetic factors. Another example from physics is the use of aesthetic factors in the visualisation of digital image processing in astronomy. In the case of theoretical physics, many physicists give importance to aesthetics in theories. To name three: Weyl, Dirac and Chandrasekhar. In the context of symmetry, Weyl and Wigner placed a premium on its related aesthetic factors. Root-Bernstein gives the example of Weyl who chose beauty as the primary criterion for a theory even 'when the facts refused to cooperate'. Dirac's often cited quotation claims something similar: 'It is more important to have beauty in one's equations that to have them fit experiments'. The physicist Weisskopf says, 'what is beautiful in science is the same thing that's beautiful in Beethoven.' In the case of chemistry, Root-Bernstein quotes the chemist Woodward who remarked, 'Much as I *think* about chemistry, it would not exist for me without these physical, visual, tangible, sensuous things.' (The things referred to here are crystals, odours, colours and so on.)

Mathematicians have consistently preferred (though not always articulated) aesthetic considerations in their formulations. G.H. Hardy is a paradigm example of one who privileges beauty: 'Beauty is the first test: there is not a permanent place in the world for ugly mathematics'. Seymour Papert believes that the emphasis on the logical part of mathematics as against its aesthetic value leads to a failure 'to recognise the resonances between mathematics and the total human being which are responsible for mathematical pleasure and beauty'. Looking at aesthetics in science from a Kantian perspective, Chernyak and Kazhdan claim that 'mathematics is aesthetic by its very nature ... *mathematics is poetry.*'

Sometimes, a judgement on what is true is based on the aesthetics of the theory or experiment. A very good example of this is Eddington. It has been suggested that Eddington's experiment, which is officially accepted as having provided the first proof of General Relativity, did not actually demonstrate conclusive proof of the theory. It was Eddington's belief in the 'beauty' of Einstein's theory, with the concomitant belief that a theory with such beauty had to be true, that led him to proclaim that Einstein's theory had been proved by his experiment.

New Kind of Science

Finally, there is yet another important component of science which challenges traditionally held views on the relationship between science and logic. Computation has always been an integral part of science. Much before modern science, computations were used extensively in astronomy in all civilizations. In fact, much of modern science and mathematics has been catalyzed by this computational, calculational spirit of mathematics and science. Astrology (in the more traditional sense in India) is also characterized by extensive calculations.

The logic of calculations is quite different from the logic of arguments or the logic that is most often associated with statements. Calculation is not always a conscious, deliberate activity. One often does not know what one is doing in the act of calculating but as one continues to calculate things 'fall in place'.

In recent times, modern science is characterised by computations of a much greater order than ever before. Thanks to computers, computation can now be done at great speeds and with much greater capacity. Computational science is now a legitimate branch of science and has even entered the domain of mathematics. Unlike the traditional model of theory, now an important, and ever growing,

part of science uses numerical and other computer simulations. One can model situations on the computer and explore how systems develop in the computer simulation. There is an enormous impact of such methods both in the pure and engineering sciences.

Such methods have been immensely influential in disciplines like biology and medicine. Pharmacy depends to a great extent on these methods to create new compounds which become new drugs. In all these cases, we can see a definite shift in the character of science. Science's intervention in nature is now largely catalyzed by computer simulations and computations. This has also led to new philosophical challenges – for example, the relation between science and reality is significantly modified in this process. For, in these cases, like in chemistry, science ends up studying the objects it creates and not the objects it 'finds' in the world. Most importantly, in this new paradigm of science, there is a new and renewed challenge to the traditional view of the link between science and logic. Exemplifying this trend, Wolfram (2002) suggests an entirely different approach to understanding the structures of the universe. He argues that these structures, including the laws of the world, are not best described by analytical mathematics but by rules of cellular automata. This means that the evolution of nature can be described as products of rules of computation. Similarly, there are computable models of the mind which attempts to understand the processes of mind as computational in character.

Logic in India

It is commonly believed that logic is unique to the Greeks and, through this, to the Western civilization. At the same time, many philosophers in the West believed that the Indian philosophical traditions were primarily about religion, mysticism and spirituality. These thinkers, including some of the most important ones in Western philosophy such as Locke, Hegel, Husserl and Heidegger, argued that Indian philosophical systems were inherently not concerned with reason, rationality or even knowledge. As is to be expected, the views of

these influential thinkers dominated the interpretation of Indian philosophy for a long time. Since logic is an exemplar of reason and knowledge, and particularly of scientific knowledge, a denial of this capability to Indians and other non-westerners effectively removed the possibility of science in these cultures.

However, most of these views on logic in India and elsewhere are completely mistaken. Logic has a long tradition in India. From the earliest times, logic was an essential part of learning. From sixth or seventh century BC onwards, Ānvīksikī – the science of inquiry – is used as the term for logic. Logic here is understood as a study of inferences and in general was about the nature of reason. Thus, it was also referred to as Hetu-śāstra, tarka-vidyā and so on. The name of Nyāyaśāstra for ānvīksikī suggests its character as the 'science of true reasoning'.

Logic in India has its roots in the art of debate. The Greeks too had a similar approach to debate and its various forms. The idea of philosophy itself arises from consideration of what kinds of debates are possible and desirable. All the Indian schools of philosophy, from the Cārvākas to Naiyāyikās (those belonging to the Nyāya school), had their own formulation of the rules of debate. It should not therefore surprise us that in the fourth century BC, Kautilya in his masterpiece *Arthaśāstra* described logic as the 'lamp of all sciences, the resource of all actions and the permanent shelter of all virtues' (Vidyabhusana 1920).

The detailed study of logic begins with the early Nyāya school. Logic was discussed not just in philosophical texts but also in texts such as the Mahābhārata. Sages, including the famous storyteller, Nārada, were often described as being experts in logical thinking, that is, experts in demonstrating an argument and arguing for conclusions. The first compiled work on the Nyāya school is Nyāyasūtra. The text is a collection of various aphorisms and may have been the work of more than one author. While parts of the text are derived from much earlier, the text as such can be dated in the second century AD.

The book deals with the following subjects: the different means

of getting knowledge, the objects of knowledge, on the nature of debates and their classification, description of the elements of syllogisms and finally, discussion of other philosophical systems. All the first four subjects engage with themes in logic. In this structure we can already see a very clear establishment of a rational discourse.

What are the valid means towards knowledge? This is the first and foremost question among all Indian schools. Each school has a position on such means towards knowledge. The materialist school (Cārvākas) claimed that there is only one proper means towards attaining knowledge and that is perception. The Buddhists claimed that there are two means: perception and inference. Nyāya accepts four such means: perception, inference, analogy and testimony.

All the schools accept that perception is the most important means to attain knowledge. We attain knowledge of the world through our sensory experiences. However, perception can be misleading. We make errors in perception; we see an object differently from different directions and from varying distances. We mistake one object for another. There are also other processes such as mirage which makes one suspicious of perception. So how do we judge that what we perceive is indeed the way it really is? This analytical approach towards the nature of perception is common to all Indian philosophical systems. The philosophical approach in such an analysis does not invoke mysticism, spirituality or the divine. Rather, they are very good examples of careful and reasoned thinking, characteristics which go to define rationality in all civilizations and at all times.

Our knowledge of the world is not only through our sensory experience. It is not that we know something only because we have experienced it. For example, if we claim to know that all crows are black based on our experience of seeing a few black crows then that claim is not based on the experience of checking whether all crows are indeed black. We make an inference that all crows are black based on a few examples. Such generalizations or inferences also give us knowledge. But just as in perception we could also make mistakes in inferring. We may see three black crows and infer that 'all birds are black' instead of inferring that 'all crows are black'. Such an inference is wrong. But why? How do we evaluate the inferences we make? How do we categorize what kind of mistakes are possible in our inferences?

Indian logic is primarily a study of these problems about inferences. While granting that inferences are a valid means towards knowledge, we should also be aware that there many types of mistakes possible in making an inference. All schools of Indian thought, including the so-called spiritual traditions, engage with this problem of valid inference.

The study of valid inferences was dominantly influenced by the early Nyāya formulation. Later on, the Buddhists formulated a more complex theory of inference. The Jainas too had their own theory of inference which is not only provocatively different but also of contemporary interest. I will describe these approaches briefly in order to illustrate the importance of the notion of reason and rationality in these ancient Indian traditions, and in an interesting way their link to what we call as scientific method today.

The Buddhists reformulated inference as a complex theory of valid signs. If we look upon smoke as a sign that there is fire then inferences, in general, reduce to finding when a sign indicates the presence of something else. Dignāga was the first to formulate the three conditions that a sign must obey in order to know that it is a valid sign. First, the sign must indeed have occurred; second, there must be similar examples where the sign and signified occur (like the example of kitchen in the case of smoke-fire); and third, there must be no dissimilar cases (if smoke occurs over water which is contrary to fire then obviously smoke is not invariably related to fire). In the next section, we will see some consequences of this approach to logic, particularly in the context of science.

The involvement of the Indian philosophers with the empirical world can be understood by looking at how these traditions operated. The study of debate is one of the important contributions of the Indian philosophical schools. The emphasis given to debates arises

out of the belief that beliefs must be argued for and not claimed on authority alone. Indian philosophy grew out of debates between different schools as well as between camps in each tradition. This process had its impact on the way the texts were written. The common mode of writing a philosophical text was as follows: first the opponent's position was described and then the various claims of this position was refuted through rigorous arguments. This importance given to the empirical world in Indian thought is further attested in the way mathematics was understood in the Indian context. In contrast to an ideal understanding of mathematics in the Greek tradition, mathematics in India was seen to be intrinsically related to the world, both in terms of meaning as well as in its origins.

An entirely new approach to logic is found in the Jaina tradition. The Jainas developed a multi-valued logic. Standard logic is two-valued, as captured in the claim that an assertion is either true or false. For example, A is either dead or alive. A cannot be both dead and alive. The Jainas developed a logic which is seven-valued. It includes the possibilities of true, false and maybe, and combinations of these three values. Interest in Jaina logic in recent times is largely because of the interest in formulating multi-valued logics in modern logic. The Jaina view is also a standpoint-view. What it suggests is that absolute true and false are not possible. Every statement is true or false or maybe true or false only from a particular standpoint. From another standpoint perhaps the same statement can take a different value. The fact that such a logical structure was developed much before modern logic understood the importance of multi-valued logic once again illustrates the amount of deep thinking about logic and rationality in Indian traditions.

Science and Indian Logic

In recent times, there have been many claims about the relationship of modern science with ancient Indian traditions. In this context, we can identify two broad claims: one is that ancient Indian civilisation was a scientific and technological society, as manifested in their advanced theories in mathematics, astronomy, metallurgy, chemistry, linguistics and so on. This is a claim that can be verified since there has been substantial documentation on this subject. It is indeed true that Indian society had developed techniques, methodologies and results in fields such as medicine, astronomy, mathematics, linguistics and metallurgy, and these developments were much more advanced than in other civilisations in those times.

The second claim is that some concepts in modern science, particularly in quantum theory and cosmology, are described by and anticipated in ancient Indian thought. This is not only a contentious claim but also one that is untenable or even undesirable. Modern science, particularly quantum theory, is a discourse which is unique in many respects and to claim that some elements of it are actually what the ancient Indian thinkers were talking about is to mistake the nature of both Indian philosophy and modern science.

However, to understand the nature of science, that is, to answer the question 'What is science?' we need to look at the structure of science, the relation between theory and the empirical, and so on. It is here that Indian philosophy, and particularly Indian logic, is relevant. While there are good reasons to critique the attempt to find contemporary ideas of modern science in ancient thought, it is nevertheless the case that contemporary philosophy of science can learn much from Indian philosophical traditions. One can fruitfully explore the possibility of drawing upon Indian philosophical traditions, particularly its rationalistic ones, to understand the nature and foundations of science. This is what philosophy of science, as a discipline, has accomplished by developing upon ancient and modern Western philosophical traditions. It is surprising that philosophy of science, in its long history, has ignored potential contributions from non-Western philosophies. It will be useful to explore whether Indian rational philosophies have anything to contribute to philosophy of science (and not to science per se). Since philosophy of science offers the best tools to understand the nature of science, it is conceivable that

Indian philosophy will in principle be useful in our attempt to understand the nature of science.

Firstly, I will begin by considering the relation between ancient Greek thought and modern science since there is a strong belief that Greek thought is intrinsically related to science, a position that betrays an unreasonable dependence on Greek philosophy in philosophy of science.

Gadamer (2001), in a series of lectures on the pre-Socratic origins of philosophy, reflects on the origins of philosophy and science in the Greek tradition. The final two essays in this collection deal with the relation between Greek philosophy and modern science, and the 'profound debt' owed by modern science to Greek thought. It will be useful to consider his arguments for it might clarify how exactly ancient philosophies are related to modern scientific thought. After summarising his view on this matter, we can then analyse the points of similarity or departure with respect to ancient Indian philosophies.

Gadamer begins with the theme of Greek philosophy and modern thought, a theme that has been a dominant influence on German philosophy over the ages. He notes that Greek philosophy should not be understood in the restricted sense which defines philosophy today. Greek philosophy not only included scientific thought but, for Gadamer, it was also the Greeks 'who instigated a world-historical decision with their own thinking and decided the path of modern civilisation with the creation of science.' This observation in itself is highly debatable even if we accept that the Greeks created the idea of science, since science in ancient India illustrated great advancement in its times. One can anticipate Gadamer's response to this caveat by noting that his idea of the scientific is subsumed under an idea of the theoretical: for the Greeks, philosophy 'meant the whole of theoretical and, therefore, scientific interest.' It has been an often repeated cliché that Indian thought lacked theory or at least the idea of the theoretical. This comment has been voiced frequently and especially when confronted with ancient Indian technology, including the metallurgical processes of making steel and zinc.

Similar comments about the lack of 'philosophy' in India have for long been a part of the western folklore. I will not respond to these debates, partly because I think some of these sweeping claims have an ideological basis. However, it will be useful to analyse Gadamer's arguments since he is arguing for the essential importance of ancient Greek thought for modern science. What I am trying to do here is to argue for the importance of Indian philosophies for philosophy of science.

Gadamer, after noting that Greek philosophy included scientific thought, continues to make the same mistake as many others before him. He writes:

> 'What separates the occident, Europe, the so-called 'Western world,' from the great hieratic cultures of the Asian countries is precisely this new awakening of the desire to know with which Greek philosophy, Greek mathematics, Greek medicine, and the whole of their theoretical curiosity and their intellectual mastery is associated. Thus, for modern thinking, the confrontation with Greek thinking is a kind of self-encounter for us all.'

There are two fundamental mistakes in this claim. First is the emphasis on Asian cultures as being hieratic cultures, namely, cultures that are essentially priestly and concerned with the sacred. There are two reasons why this claim is obviously wrong: one was the living presence of philosophically sophisticated rational traditions of Indian philosophy and the other was the presence of a vibrant scientific and technological culture in ancient India. Secondly, Gadamer compounds this mistake by categorising the difference between the Western world and the Asian one by the 'new awakening of the desire to know.' It is not worthwhile to attempt to refute this obvious absurdity but we can note that Indian philosophy, Indian mathematics, Indian medicine, Indian chemistry and metallurgy, and so on, were all activities that were essentially and intrinsically concerned with the nature of knowing. All the Indian philosophical traditions, including those which are seen to be concerned more with

the spiritual, have critical formulations of a theory of knowledge. This is true, for example, even of the logical tradition. Furthermore, the tradition of Indian logic is not only deeply committed to knowing, but also to theoretical formulations of categories such as inference, invariable concomitance, empiricism and so on.

However, what I want to query further is Gadamer's argument linking modern science and Greek philosophy. Greek thought, for Gadamer, exhibits a confrontation 'between the intelligible world and the masterable world.' Galileo is often called the father of modern science. His belief in the mathematical nature of the world as well as his attempts to bring the mathematical together with the empirical influenced the shape of modern science for centuries to come. Gadamer sees this move by Galileo as one that rejects the anthropocentrism that was an essential part of Aristotelian science. Gadamer believes that in the confrontation between modern science and ancient tradition, it is the issue of objectivity that comes to the surface. It is well known that scientific methodology is fundamentally articulated in terms of objectivity, which includes the possibility of knowing something as an object. To know something as an object is to be able to access it some particular way. For Gadamer, it is precisely the limits of objectification that is the 'relevant and persistent heritage of Greek thinking.'

Four themes are related to this problem of objectification. The first concerns the body as object. Gadamer makes an interesting point here that Greeks did not have terms for object and objectivity, and even for a 'thing'. The word that referred to all these terms was pragma, which 'refers not to that which stands over against us or opposed to us as something to be overcome, but rather to that within which we move and that with which we have to do.' Gadamer notes that this particular way of viewing the world has been lost in modern science. The second theme is that of freedom, the third is the role of self-consciousness in modern thought and the last is language. Modern thought gives a 'methodological primacy' to self-consciousness, as well exemplified in Descartes' formulation of methodological

doubt. However, there is no obvious reason to accept the uncritical acceptance of self-consciousness; Gadamer finds ancient Greek thought a way to critique this uncritical acceptance, thereby finding the limits to self-knowledge. Language is an important theme in this analysis because, among other reasons, language captures the essence of non-objectivity.

Gadamer attempts to find certain points of conflict between ancient Greek philosophy and modern science but in doing so only reiterates the 'enduring relevance' of ancient thought to modern science. In particular, the Greek tradition gives access to a way of integrating the empirical sciences with the praxis of social life. Gadamer is basically dealing with the originary question, going to the origins of Greek thought and finding its relation and relevance to modern thought. And in searching among the ruins of the Greek origins he is doing something that is shared by many other philosophers, particularly philosophers of science. The title of Gadamer's book – *The Beginning of Knowledge* – is an indication of this argument that traces the origins of particular modes of thought associated with knowledge to the Greeks. It is through this that he finds a common measure of engagement with science, since science is fundamentally concerned with knowledge about the world. The originary question must be important for philosophy of science – at the least to explain why it draws exclusively upon Western philosophy to understand the nature of science. Just as Gadamer's title suggests what idea is to be found in ancient Greek thought, philosophers of science might have as well titled their works – "The Beginning of Science" – and placed this within Greek thought.

One reason to explain this complete denial of other philosophical traditions in mainstream philosophy of science is due to the belief that modern science is a product of Western civilisation and hence any analysis of it is best done by the philosophical traditions of the same civilisation. This is the originary issue for philosophy of science. This particular point of view is further strengthened by the common observation that natural science grew out of philosophy. However,

this observation emphasises common origins of particular kinds of intellectual activities while ignoring the reasons as to why science broke away from traditional philosophy. In the history of modern science, there have been more attempts to show that the distinctive nature of scientific character was radically different from philosophy than attempts to show that they were similar. This is a potential paradox for philosophy of science: it insists on using philosophical insights from traditions whose rejection in the first place catalysed modern science.

There are two kinds of originary questions. One is about civilisational origins, which is the argument that modern science and Western philosophy are in kinship because of common civilisational origins. We have seen the problems with this view. The other is conceptual origin, where there is a common conceptual and methodological space shared by science and some philosophical traditions. Regarding civilisational origins, it is not true that Indian traditions do not directly have a kinship with modern science – in the last chapter I will discuss the multicultural origins of science. Moreover, if conceptual and methodological spaces are concerned, there is much in common between Indian rationalist traditions and the philosophical foundations of modern science.

Philosophy of science is first and foremost philosophy. It is the act of philosophising about science. To philosophise is to invoke the universe of philosophy to reflect on some subject matter. It is to deploy ideas and concepts from philosophy, to follow certain accepted patterns of argumentation, to explore the meaning of the subject from outside it in some sense and understand its foundations. Philosophy of science thus explores the foundational structure of science. To do this effectively, what kind of philosophy would be most useful? That is, what should be the nature of a philosophy that can best understand science?

There are two possible ways by which we can philosophically reflect on science. We can bring a prior set of philosophical categories through which we analyse science or we can identify some basic

concepts in science whose philosophical relevance can then be studied in detail. The latter approach, which is quite common in philosophy of science, would be based upon the fact that science and philosophy (as well as common sense and other non-specialised activities) share a common space, have common concepts and, to some extent, common vocabulary and methodology. However, we need to note that as far as these common concepts are concerned, concepts such as mass, energy, properties, laws and so on, both science and philosophy understand them quite differently.

To philosophically reflect on an idea is to understand the idea through the vocabulary, conceptual structure and modes of argument present in a philosophical tradition. In this broad sense of the meaning of philosophical reflection, there is strictly little relevance for common origins. In principle, say, we have a scientific idea which we want to philosophically reflect upon. Different philosophical traditions look at the same concept according to the concerns of that tradition. For example, the questions and arguments put forth by the Western phenomenological tradition are radically different from those posed by the Western analytical tradition. Philosophy of science has shown great resistance to incorporating the phenomenological tradition as compared to the analytical one.

The common origin argument for using Western philosophy can also be easily extended to the use of Indian philosophy for the simple reason that science uses and deals with concepts and processes that share a common space with Indian philosophical traditions also. Ideas such as inference, reasoning, knowledge, causality and so on are philosophical themes within Indian traditions as well as in science, and so in principle there is a shared space which allows the first step of philosophising. Furthermore, there are philosophical traditions within the Indian systems which are far closer to certain Western philosophical traditions in comparison with other Western traditions. For example, we could argue that Nyāya is more closer to logical and realist schools of Western philosophy compared to certain idealist and phenomenological traditions in Western thought.

Is there a particular philosophy that is best suited for understanding science? I do not think one can identify any particular tradition or a particular set of ideas as best representing the philosophy of science. Different ideas and different traditions develop more *complex* and nuanced ways of understanding scientific activity. Can there be a philosophy intrinsic to science? It will be very surprising if there is a particular philosophical tradition that best voices science. Realism would be the closest doctrine that one might choose for this role but the complexities of scientific realism actually raises more questions for philosophical debates on realism. Pragmatism is another tradition that is again strongly reflective of scientific practice but pragmatism in philosophy is a much larger system of thought.

Given all these reasons, it seems reasonable to believe that the role of philosophy in science is to reflect upon scientific ideas and practice with the help of certain philosophical tools. Therefore, it seems only reasonable that tools from Indian philosophical traditions should in principle be as important as tools from other Western traditions. After all, not only did the Indians engage actively in scientific and technological issues but they also had a flourishing practice of mathematics and astronomy. Moreover, as described earlier, Indian philosophy was deeply engaged in the development of disciplines such as logic, epistemology and philosophy of language.

I think we can reasonably hold the position that certain aspects of Indian philosophy are not only relevant to a foundationalist description of science but that they also share something in common with scientific methodology. There are many pointers to this and in what follows I will only briefly indicate these reasons. We can begin with the nature of doubt and its relation to science. In Western philosophical tradition, as well as in science, doubt is an important theme. Descartes inaugurated the move towards certain knowledge by beginning with doubt and thus formulated a methodology of doubt. Indian philosophical systems also begin with a priority to the nature of doubt. There is a great deal to be doubted: our perceptions, reasoning, evidence, inferences and so on. For the Indian logicians, exemplified by the Nyāya school, doubt is the beginning of inquiry. The purpose of inquiry is to resolve a doubt and reach a state of certainty. The Nyāya formulation of doubt is rich in many ways. Doubts are framed in an interrogative form, which in modern terms can be seen as belonging to the 'alternative' type of questions. Doubts are classified into different kinds. Doubt and its resolution are an integral part of the rich tradition of debate in Indian philosophy. The steps to eradicate doubt as part of debate embody a rational strategy, which includes the use of empirical observation, some fundamental principles as also the well-known *nyāya* five-step process, usually referred to as *nyāya* 'syllogism'.

Indian theories of doubt range from the sceptical mode in some Buddhist schools to a pragmatic approach by philosophies such as Nyāya. Descartes' methodology of doubt has been extremely influential in philosophy of science. The Nyāya approach to doubt is pragmatic in nature and is closely related to the relationship between doubt and action. The American pragmatist, Peirce, shares a great affinity with Naiyāyikas (those belonging to the Nyāya school) since his response to sceptical doubt is very similar to theirs. The relation to scientific method is manifested when we analyse the nature of scientific doubt, which is also highly pragmatic in character. Even in the fundamental description of the nature of doubt, science and Nyāya share similar concerns.

The rationalist tradition in Indian thought is essentially related to the logical tradition since logic was about the nature of reasoning, argumentation and the art of persuasion. As mentioned earlier, the greatest contribution to Indian logic came from the Nyāya and Buddhist schools. Inference was the central concern of these logicians. How do we infer? What do we infer? How can we distinguish between a valid and invalid inference? The early structure of inference discussed by the Nyāya school leads to the well-known five-step formulation of *nyāya* method. A qualitative shift in the understanding of inference occurs with the formulation developed

by the Buddhist logician Dignāga, whose basic model came to be the standard structure for studying inferences. Dignāga's innovative description of inference, described in the earlier section on Indian Logic, was through the notion of 'sign' and he should be understood as exploring the relation between logic and semiotics.

There are many themes drawn from Indian logic which are relevant to philosophy of science. These themes include the differences between Indian and Western logic, induction/deduction structures in Indian logic, the idea of necessary relations which are lawlike, reductio reasoning, the role of fallacies, the meaning of definitions and of properties. In these discussions, we can isolate many common themes from Indian logic that are of potential interest to understanding the nature of science.

This relation between logic and science has filtered so deeply into the social imagination that we normally tend to associate science with (western) logic. But in so doing, it is reasonable to believe that rather than discovering logic in science, philosophy of science may have transplanted logical themes on scientific practice.

In searching for logic in science, philosophy of science has also been guilty of not critiquing its understanding of logic itself. Traditional concerns of philosophy of science have demanded that science be logical. This makes perfect sense when viewed along the historical trajectory of Western rationalist tradition as well as the growth of logic. However, this is also how Western logic differs markedly from Indian logic. I capture this difference by the use of the phrases 'logic in science' as against 'science in logic'. The fundamental argument that follows is that philosophy of science, based on Western philosophy and logic, is actually searching and demanding for logic in science. In contrast, Indian logicians are demanding that logic be scientific.

It is this question of priority, whether logic comes first or science, that is at the heart of the difference between Indian and Western logic, a difference that is characterised by the question: *Should logic be scientific or should science be logical?* This question might make sense

only if we clarify the meanings of the terms logic and science. It is no accident that this naming of something as science or logic has been a serious matter of contention in various debates in the contemporary world. Here, I want to use our common notions of science and logic, and use this to raise the question of priority. If by scientific we mean both an empirical and theoretical mode of reflection, then logic is not scientific for Western logic since the essential character of logic is to be outside the domains of the empirical in an explicit manner. Thus, for Western and modern logic, the issue can only be of the logical in science.

In contrast, for Indian logic, the central concern is to make logic scientific. This implies that logical statements have to respond to empirical concerns. While this move militates against the very notion of logic in the Western tradition, it is precisely this demand on logic that makes Indian logic essentially correlated to scientific methodology.

Here we can ask whether we are trying too hard to fit Indian logic and science. This question becomes important when placed in the contemporary intellectual scene where there is a claim that modern insights were anticipated in ancient cultures. I am explicitly against accepting such claims and the responsibility to carefully argue for these claims rests on those who make these claims. Conscious about this problem, we can first note that science continues to make 'simple' inferences of the kind that logic, particularly Indian logic, dealt with. A question commonly encountered is: How can examples from ancient Indian logic matter to science today? The simple answer is that there are numerous inferences in science that are conceptually similar to those ancient examples, as well manifested in Newton's laws themselves.

There is yet another common concern of Indian logicians and modern science. This has to do with something foundational about the activity of science. Indian logicians had two great worries: one, the relation between the sign and the signified, and two, the possibility of moving from an observation to saying something about it. The first

question is the foundational question of semiotics. And the person who was such an influence in the study of semiotics and its relation to logic was Peirce, the same person whose views on doubt resonated with that of the Naiyāyikas. For both the Indian logicians and Peirce, logic and semiotics were essentially related. Indian logic privileged the notion of a 'natural' sign, or a sign which has some necessary connection with the signified, whereas in the Western tradition the arbitrary nature of the sign became extremely influential. This influence is clearly seen in the way both mathematics and logic became dependent on the idea of arbitrary symbol.

Not only is Indian logic a matter of semiotics, so also is science. The semiotic character of science is not often discussed. However, there is much in science that is played out through the language of semiotics. We need look no further than interpretation of experimental observations, where we see a mark that stands for something else as evidence for the existence of an entity or phenomenon. Since science extends observation into the domain of instruments, we need to learn what the instrument is 'seeing' based on its output. From an experimental observation, how can we be sure that the mark or sign does indeed refer to a particular entity, for example, an electron? Dignāga gave three conditions for a sign to be a logical sign. If we extend this question into the semiotics of experimental observation, we can see that Dignāga's conditions of similarity and dissimilarity cases do the same work as the demand in science for replicability of experiments and the importance of null-results.

The other fundamental concern for Indian logicians – the validity of making generalisations from observations – indicates the problem of moving from experimental observation to theorising about them. Generalisation is a common and important step in theory formation. Some observations can be generalised and others cannot. Why is this so? What kind of evidence allows generalisation? While these are questions that overlap with the problem of induction, the Indian approach to these questions differs in significant respects. This issue of the experiment–theory link in modern science shares common

conceptual problems with Indian logic. Thus, we find a rich interface between Indian logic, semiotics and science.

There is yet another important connection between Indian logic and science. It is clear that the Indian logical structure is fundamentally concerned with explanation. The differentiation of inference into inference-for-oneself and inference-for-others also makes this explicit. Now, what seems interesting is that the Indian logical structure is not just any theory of explanation but one which matches very closely with the structure and aims of *scientific explanation*. The early *nyāya* five-step process has a strong correlation with the deductive-nomological model of scientific explanation. The Buddhist reworking of the inferential model is also concerned with generating explanation of the relation between generalities. The connection between Indian logic, semiotics and scientific explanation shows once more the close connection between the concerns of Indian logic and what we call as scientific methodology today, thus reiterating once more that demanding logic to be scientific is probably a more faithful description of science than prioritising the belief that science should be logical (Sarukkai 2005).

References and Further Reading

For stories on scientific discoveries, see:

Gratzer, Walter. 2004. *Eurekas and Euphorias: The Oxford Book of Scientific Anecdotes.* Oxford: Oxford University Press. Many websites have such stories of discoveries in different disciplines.

On Creativity in science and other creative fields, see:

Csikszentmihalyi, M. 1996. *Creativity: Flow and the Psychology of Discovery and Invention.* HarperCollins.

For science and aesthetics, see the collection of papers in:

Tauber, Alfred. 1996. *The Elusive Synthesis: Aesthetics and Science.* Kluwer.

For a classical text on aesthetics, see:

Beardsley, Monroe. 1958. *Aesthetics, Problems in the Philosophy of Criticism.* New York: Harcourt, Brace and Company.

Wolfram, Stephen. 2002. *A New Kind of Science.* Wolfram Media.

Gadamer, Hans-Georg. 2001. *The Beginning of Knowledge*. Trans. R. Coltman. New York: Continuum.

Trusted, Jennifer. 1979. *The Logic of Scientific Inference: An Introduction*. London: The Macmillan Press.

For material on logic, see:

Chattopadhyaya, D. P. 1991 *Induction, Probability and Skepticism*. Stony Brook: State University of New York.

Cohen, Morris and Ernest Nagel. 1972. *An Introduction to Logic and Scientific Method*. Delhi: Allied Publishers.

Peirce, C. S. 1955. "Logic as Semiotic: The Theory of Signs." In *Philosophical Writings of Peirce*. Ed. Justus Buchler. New York: Dover Publications.

Useful background information on Indian logic can be found in:

Hayes, Richard. 1988. *Dignaga on the Interpretation of Signs*. Dordrecht: Kluwer.

Keith, A. B. 1977. Reprint. *Indian Logic and Atomism*. New Delhi: Oriental Books Reprint. Corporation.

Matilal, Bimal. K. 1985. *Logic, Language and Reality: Indian Philosophy and Contemporary Issues*. Delhi: Motilal Banarsidass.

Mohanty, J. N. 2002. *Classical Indian Philosophy*. Delhi: Oxford University Press.

Phillipps, S. 1997. *Classical Indian Metaphysics*. Dehi: Motilal Banarsidass.

Sarukkai, Sundar. 2005. *Indian Philosophy and Philosophy of Science*. Delhi: CSC/Motilal Banarsidass.

Sarukkai, Sundar. 2008. "A Semiotic Interpretation of Indian Logic." In *Logic, Navya-Nyaya & Applications: Vol 1*. Eds: M. Chakraborty, et al. London: College Publications.

Vidyabhusana, Satis C. 1920. *A History of Indian Logic: Ancient, Mediaeval and Modern Schools*. Calcutta: Motilal Banarsidass.

IV

Science and Reality

Philosophy begins with the attempt to understand the nature of the real. The first philosophical insight arises from the recognition that reality is much more complex than what we perceive through our five physical senses. It is indeed true that what we see is not what we get. Our common sense realism suggests to us that we perceive a world around us, we perceive objects and events, and that we also infer the presence of things which we do not immediately perceive. Our 'common' sense of reality guides our action – we pick up a fruit to eat because we take for granted that the fruit we see in front of us is indeed there. This sense of reality also acts as an impulse to our first steps in learning and creating language. We use words to point to things in the world.

So, in a sense, there really seems to be no serious problem about reality. One could say that reality consists of everything that we perceive with our senses. Why then do philosophers make such a big deal about the nature of reality? First of all, what we perceive is often not the way things 'really' are – a green leaf looks different under different lights, it looks different when viewed from different perspectives and from different distances. Colour blind people do not see the colours that we see and so might not think that an apple is 'really' red. We often see examples of how different people see the same things in widely differing ways as well as perceive that which is not perceived by everybody. For example, somebody might say that ghosts are real. For many people, there are ghosts. They will

even describe them in great detail. But many others believe that there are no ghosts. So we have a dilemma – how do we choose between different claims of what is there in the world?

The problem of what is there is not restricted to odd objects like ghosts. There are various other entities which we talk of as if they are real: space, time, god, numbers, sets, atoms, electrons, DNA, genes, molecules, memories, thoughts, ideas, mind, colour, shape, smell among others. These 'things' are not as real as tables, chairs or trees. But they are not 'as real' in different ways – for example, the way in which an atom is not like a chair is very different from the way in which the mind is different from the chair. In the former, we are told that atoms are objects but they are very tiny and cannot be perceived by our senses. On the other hand, the mind is not perceivable not because of its tiny size but because of its very nature. So one major task of philosophy is to list what kinds of things there are in this world and once it does this it also has to give reasons for believing that such things exist. The project of listing what kinds of things there are in the world is called ontology, which is a sub-discipline of philosophy. And the ways by which we come to know these things mostly has to do with the study of knowledge, which is called epistemology.

For the purposes of the discussion on science and reality, there is one more element that I should mention here. The problem is not just in knowing what really is present out there in the world but in the possibility that our perception may be adding something to what is out there. Imagine this much discussed example: if our eyes are naturally endowed with a red filter then everything we see will be mediated by this colour. So when we see a fruit as being orange in colour it might actually be yellow because red and yellow together yield orange. This is a simple example to suggest that we might be mistaken if we assume that our perception of an object matches how it really is.

A simple thought exercise might convince you of the difficulty of this problem. Imagine, if you can, how a room looks to an insect which might be sitting on your chair just like you. If the insect has

a complex eye system then it is quite possible that the way the room appears to the insect is very different from the way it appears to you as a human subject. For example, the room might appear curved to the insect since the reason why humans see the world around them as flat is influenced by the nature of the lenses in our eyes. Therefore, if the structure of our body determines how we perceive the world then what guarantee is there that the objects we perceive are indeed just like the way the objects are? In other words, if we had had a different body structure, say a body with three eyes with one eye in the back of the head, we would have seen the whole world in a completely different manner and hence the list of things that such a creature would list would be different from our present description of things in the world. We don't have to struggle to imagine this situation – just think of how the world would look like to a fish, for example.

Complicating this problem is the presence of the mind or, for those who do not believe that there is something called the mind over and above the body, the problem related to mental states. As we saw earlier in the chapter on logic, we seem to have a special capacity for knowing more about the world than we actually perceive. For example, even though I do not perceive fire I can know that there is fire by seeing smoke; even though I have not tasted all mangoes which are ripe I know that ripe mangoes are sweet. There are also other kinds of things that we seem to come to know through our mental activity. For example, our knowledge of mathematics seems to be derived entirely through the activity of thinking. Thinking and imagination are two ways by which we seem to discover new realities. And ironically what we come to know through thinking seems to be much more certain than what we come to know through our perception. Mathematics is the best example of this. Now this mental perception does not depend on other conditions as in the case of perception of an ordinary object which is influenced by light, distance and perspective. Mental perceptions, as in logic and mathematics, seem to give us certainty that our ordinary perception cannot.

There are two consequences of this observation: one, we have a capacity to access reality through this ambiguous thing called the mind and two, just like in the case of body we cannot be sure how much of what we perceive is moderated by the mind. In other words, just like a permanent red filter of the eye can influence how we see things in the world, a permanent filter of the mind can also influence how reality is organized for us. What it suggests is that there is really no reality out there which is independent of us. Everything that we perceive is influenced by the structure of our body and of our mind. And hence to conclude that just because the world appears to us in a particular way means that the world is really like that is a hasty conclusion. This has led some philosophers to claim that everything that we perceive is actually a product of our mental process and therefore is created by us in some sense. According to this view called idealism (there are many schools of idealism) not only is there no guarantee that what we see is how the world really is like but there is no guarantee that there is a world at all other than the perceiving individual!

The above introduction is a preliminary philosophical understanding of reality. In the case of science, there is a completely new dimension to it. Science believes in a robust version of common sense reality – it accepts that there is a world outside us which is also independent of us. But it also realizes that our perception might distort the reality of the object – that is, the way the objects *really* are. It also recognizes that the limitation of our perception means that there is a much richer world of the real out there which our senses alone cannot detect. Because of these presuppositions, science creates a very rich world of reality, one in which there are not only perceptible things but also unperceived ones such as atoms and electrons. There are also mathematical things which are real for them; the world of reality which is needed for science is actually far more complex than ordinary realism can hold. Since this is one of the most unique and perhaps the most defining characteristic of science, I will discuss this complex relation between science and reality in some detail in this chapter.

For philosophy too, descriptions of reality are far more complex than a mere listing of things in the world. To understand reality we need to describe what is common to all real things. For example, if there are many red things we can ascribe redness as being common to all of them – this is the reason why we see all of them as red things. Similarly, when we believe that so many things around us are real, we can ask: what are the common characteristics that they all share? Just like a red object A and another red object B share a common colour, what exactly does a real object C and another real object D share – as far as the status of reality is concerned? This is the question that motivates the study of metaphysics, which is a branch of philosophy that uncovers the structures of reality.

Both the ancient Indian and Greek philosophers described this nature of reality with the help of Categories. These categories are what are common to all real things. Substance is one category according to which every real entity has something called substance. The nature of this substance is itself a matter of great dispute over centuries but nevertheless it is a primary category in the sense that everything real has substance. Substance does not mean physical matter; it is an abstract view which is sometimes understood as a substratum on which other categories like properties (shape and colour of an object, for example) are 'attached'.

Categories are the most basic building blocks of reality. They give us an account of what is common to all real entities. Such descriptions of the real also allows for the possibility of numbers to be real (they could be abstract 'things', for example), for God to be real (even though God may not share any characteristics of physical reality with humans) and so on. The building blocks of reality are the categories; for Aristotle, the categories included substance, quality, quantity and relations. For the Indian realist school, Vaiseśika, the categories included substance, quality, relations (such as inherence) and universals. This classification tells us that these are the basic building blocks of everything that is real, where the real is not to be reduced to what we perceive. So space and time can be real, numbers

and God can be real, there can be universal colours, concepts can be real. Science too has a strong commitment to the reality of many unobservable entities such as space, time, numbers, concepts and so on. The significance of scientific descriptions of the real lies in the ability to describe what we do not and cannot directly perceive.

Descriptions of Reality

Suppose we begin by accepting that there is a real world around us populated by many different entities. Accepting their reality as a matter of fact means that every time we see these entities we do not ask whether they are real. Usually, we believe that for the most part what we perceive is indeed present in the world. Hallucinations and mirages are only exceptions and not the rule.

Once we perceive this reality around us, we describe it. And different activities have different ways of description. A poet on seeing a flower might describe it in a particular way whereas a biologist on seeing the same flower might describe it differently. Descriptions use concepts – the poet might use the concept of beauty while talking about the flower while the biologist might talk about the family to which the flower belongs. The point is that there are many ways of describing the real and these different kinds of descriptions define fields such as poetry, literature, social sciences and the natural sciences. In other words, the same thing can be described in different ways: you could have a scientific description, a poetic description, a literary description, a mythical description, a historical description, a social description. Equivalently, we can say that descriptions can be mythical, mystical, mathematical, aesthetic, ethical, quantitative, qualitative and so on. And within each of these types of description you could have other sub-types. For example, a scientific description could have a physical description, biological description, chemical description.

Thus, it is not just a mere matter of perceiving something to be real. The way we describe that real can be very different for different people. Chemists do not normally describe chemicals in terms of 'tastes' such

as the beauty of their colour or the sensibilities surrounding their smell. Scientific description is primarily a quantitative description – it is a description that is about measurable quantities whereas a poetic or aesthetic description is about immeasurable qualities, like how something 'feels'. Scientific description is impersonal whereas aesthetic descriptions often are personal and invokes descriptions of personal experience of pleasure, pain, joy and so on. Scientific descriptions often have to be justified through arguments, evidence and are studiously impersonal. But while these are broad differences between the scientific description of the real and other modes of describing the real, nevertheless when we look into the matter closely we find some overlap with each other. Scientific descriptions invoke the aesthetic as we saw in the earlier chapter, and literary descriptions engage far more with the real than is often accepted (this will be discussed in this chapter).

So now we have another distinction between science and other activities. They differ through the ways by which they describe the real. What follows in this chapter might illustrate the complexity inherent in all descriptions of the real but first we have to recognize that the 'Real' can indeed be defined in different ways. A useful analogy to understand this is as follows: think of looking at the world through different windows in a house. Each one of the windows shows us one view of the world around us and all the views from the windows need not and will not be the same. Imagine a house with one side facing high mountains and deep valleys and another side overlooking a sea. A person who sees the world through the windows which open out to the mountains will describe a different world than the one who sees only the ocean. The point is that reality is multi-faceted; specific types of descriptions show us one face of the complex real. Thus, literary imagination shows us one aspect of the real, scientific imagination shows us another and the mythical imagination yet another.

In the remaining part of this chapter, I will explore the nature of the scientific engagement with reality. To illustrate this complexity,

I will begin with a very simple example of matter and space, and show how science has tried to describe these two basic entities in the world.

The 'Reality' of Matter

The history of matter is a long and tortuous one. Philosophy has had a long history in describing the nature of matter. The development of science led to radically new ways of understanding matter. I will give a brief historical account of how philosophy, both Indian and Western, and science described matter. Since matter and space seem to be essentially interrelated, I will discuss theories of space and then consider how the notion of matter was defined in contrast or in conjunction with it. Finally, we will see how the modern conceptions of matter arising from modern physics offer a radically new way of conceptualizing matter.

Space and matter

Let me list some themes common to space and matter. We talk of space as if it exists around us. In our general comprehension, we make an ontological commitment to an entity called space. We even claim to know some of its properties. We believe space is all-pervasive, has no conceivable end. If there was a natural boundary to space, we could ask, what is beyond this boundary? While this may seem to 'prove' that space is infinite, it is really not so simple. In the Greek tradition, it was largely believed that space was finite. There is an interesting connection made by some philosophers between the spread of space and the nature of light. It was believed, following the Italian philosopher Campanella, that 'spreading of light is the basis of extension in space,' thereby leading to the belief that study of geometrical optics was the key to understanding the universe (Jammer 1954). This view directly led to the development of optics in the thirteenth century.

In the Indian tradition, space was always conceptualised to be infinite. In the Vedic tradition, space is of prime importance.

First there was space and creation followed the existence of space. This can be contrasted with the creation myths in other religions. For the Hebrews, the beginning, the first condition for creation, was the Act and for the Christians it was the Word. For the Vedic tradition, in the beginning was Space. The Rg Vedic story of creation is well known. In the beginning, before creation, there was only 'impenetrable, nameless density', 'unfathomable' and in a darkness which is characterised as 'darkness in darkness' (Kramrisch 1991). The turbulent collisions in this fluid give rise to the golden egg, *hiranyagarbha*, which floats in this flood. In this creation myth, space is the first created entity. The world is formed from substance in 'which motion is present'. Indra creates the heaven and earth by first separating and then supporting the two distinct domains. The space created between heaven and earth was called *antariksa*, that which lies (or shines) between. This is a bounded space, bound on its extremeties by heaven and earth.

There is no mention of the word *ākasa* in the Vedas and the use of this word is post Rg Vedic. In Upanishads, *ākasa* is a subtle substance and is the fifth element, the other four being air, fire, earth and water. Like the other elements it can be perceived through sensations but is not independent of the four elements. Rather, it inheres in them. In the Indian traditions, there is this recurrent idea that space is perceptible through the sensation of sound. It is sound which makes space manifest. The Upanishads also consider time as being a 'part' of *ākasa*. As far as its extension is concerned, space is seen to be without limit and without dimension. In terms of existence, *ākasa* is second only to the *Brahman*, the ultimate reality, and in fact supports this reality.

The central place given to *ākasa* is seen in *Chandogya Upanishad*, which claims that all beings arise out of *ākasa* and return back to *ākasa*. The ontological priority to *ākasa* can thus be seen in this view that without *ākasa* there is no possibility of perceiving the external world. Again in the *Chandogya Upanishad* there is this influential, symbolic picture of the human being as the city of Brahman. Within

the human, there is a small lotus flower within which is a small space called the *hrdaya ākasa*. This small space has no measure but holds the entire cosmos within it and extends as far as cosmic space. This is an important picture for it suggests two essential points that distinguish the Indian view from the Western ones. First, the quality of space is not seen to lie *necessarily* within the concept of extension. Even a 'very small' space is seen to be essentially the 'same' as the all-pervading cosmic space. Secondly, this emphasises the importance of the idea of 'inner space'. This notion of the inner has interesting connections through many Indian traditions. For example, yoga can be seen as a philosophy of the inner in many ways, including an obvious material way of perceiving the inner body. This inner conception of space had an intrinsic relation with the architecture of temples symbolising sacred spaces. The inner most sanctum sanctorum of temples is the *garbhagraha* and the womb-character of this is equivalent to the inner space *hrdaya ākasa*.

So two essential properties of *ākasa* can be noted at this point. One is the emphasis given to the idea of the inner, which is one example among many different kinds of spaces, different from but similar to physical space. The other is the belief that *ākasa* can be experientially accessed. These points are of particular interest especially in contrast to Western conceptions of space. There is yet another characteristic of space which is different in Indian and Western thought. This has to do with space and measurement. In the West, space was determined by the idea of the interval till the early 19th century. It was only in mid-19th century that the encompassing nature of space was conceptualised although this was part of some earlier architectural practices. In contrast, the encompassing nature of space, that is, the idea of surrounding a point rather than movement from a point to another (the idea of an interval), had always been a characteristic of Indian views on space (Winter 1991). One can perhaps see a parallel between matter and measurement in the development of the idea of matter.

Plato had many original ideas about the nature of space. Plato's

view of space as a container, which is a receptacle for things, was influential in Greek and the later Western views on space. Plato had many metaphors to describe space and one of them was space as the 'nurse of becoming'. The philosophical problems of change, championed by the Eleatics (Zeno in particular), was instrumental in this image since 'Becoming' constituted change and 'Being' signified permanence. Plato also believed that there was no empty space, that is, space without any matter and objects within it. Further, space had no qualities, was entirely homogenous and immutable. Borrowing from Greek cosmology, Plato believed that space was spherical and since the Greek cosmos was finite, space too was seen as finite. Finite space might seem to naturally lead to the question: what is beyond the boundary of this finite space? For Plato, this was not a problem since beyond the boundary there is no 'place' for objects to exist and since there is nothing called empty space there is really no conceptual problem in positing finiteness of space. Finally, space for Plato was everlasting and indestructible, characteristics that are common to many other Western and Indian views of it.

Aristotle is arguably the most important figure in terms of his influence on Western thought. His ideas on space prevailed for over a thousand years and, because of his influence, also inhibited the acceptance of new ideas about space. Like Plato, Aristotle too believed in the existence of an entity called space. Aristotle's seminal contribution was his elaborate theory on the idea of 'place' occupied by things. Space was the 'sum' of all such places.

There is no notion of place without objects. Thus, for Aristotle, there can be no possibility of empty space, that is, space empty of things. But what exactly is the relation between space and a thing? Consider an object. It has a boundary. What we commonly perceive as space is that which surrounds the object. Aristotle extends this visual picture into a definition of place, which is a part of space 'whose limits coincide with the limits of the occupying body' (Jammer 1954). Thus it is like a sheath, a covering over an object. It is not a part of any object but corresponds to that which embraces

it. It is neither smaller nor greater than the object and is completely separable from it.

Aristotle is also acknowledged as the father of physics as a discipline. But his physics was quite different from the physics we know now. His views on space were very instrumental in the kind of physics he developed. In his time it was believed that there were five elements, namely, earth, air, fire, water and space. Each of these elemental spaces, according to Aristotle, had a natural place of their own. Motion of these elements was explained by saying that motion was nothing more than the natural tendency of these elements to move towards their natural places. Thus air and fire tend to move 'up' and heavy things like water move 'down'. The qualitative distinction between up and down, for example, immediately meant that space could not be isotropic. Neither could it be homogenous. From Plato, Aristotle borrows the ideas of finiteness of space and the impossibility of empty space. One of the most significant consequences of Aristotle's view of space was that space had a causal role in motion; it was efficient cause of motion because of the movement of the elements to their natural places. These views on space became enshrined in the Western tradition and it took over thousand years for them to be challenged and overturned.

In the corresponding period, many Indian schools developed various versions and modifications to the Upanishadic view of space. A striking contrast is offered by the early Theravada Buddhism who saw *ākasa* not as a real entity but only as a concept. The idea of space had more to do with the nature of objects, in particular the limitation of the extension of matter. Thus *ākasa* for them was a potentiality. It was neither ether nor matter. This concept was two-fold; in keeping with other Indian schools, they saw the two folds as being inner and outer spaces. The state of potentiality of *ākasa* described space as a condition of possibility – possibility for matter to occupy it and a possibility for being occupied.

The different kinds of space, as mentioned earlier, embody different essential qualities. The Jainas defined two types of space:

lokākasa, the space of the world, consisting of all the substances along with the space between them, and *alokākasa*, the infinite space that exists beyond *lokākasa*. The Jainas also had an atomic view of space. Space was seen to consist of atoms, *ākasanu*. These are to be seen as spatial points (Bhattacharya 1999).

A different variety of a theory of space was given by the Nyāyas. Firstly they distinguished between 'ether' and space. Ether was identified with the Upanishadic view that space is sensorially accessible through sound. Thus ether has the quality of sound whereas space had no specific quality, although it has been noted that there is sometimes no clear distinction between ether and space. Space was seen as substance: independent, eternal and all pervading. For the Nyāya, space occupies a privileged position in their ontology. They believed that space had to be inferred since it could not be detected through the sensations (it was ether which was identified with the quality of sound). The primacy given to inference is also consistent with the centrality of logic for them. Their argument for inference is that nothing, including ideas and language, can be explained without postulating the existence of space. They believed that the presence of space was what generates in us the very ideas of distance, the notions of far or near. That is, our perception of the world, the categories by which we make sense of it, are actually a by-product of the nature of space around us. This is strongly emphasised in their statement that space is the cause for existence of any entity (Keith 1977).

The emphasis on different kinds of space is also exemplified by the Yoga Vasista, where different kinds of spaces were identified: mental space, space of consciousness and physical space. (This can be contrasted with the later development in the context of mathematics where geometrical space was distinguished from physical space.) One of these spaces, the space of consciousness, is what gives us knowledge about that which is existent and non-existent. There is also a formulation of *paramākasa* in this tradition. This is the 'highest kind' and is an attribute of the supreme. This space has no conception of beginning, middle or end. Interestingly, it is also mentioned that

this space is absolutely quiet – perhaps taking it away from immediate sensation since space was thought to be identified with sound. Yoga Vasista also privileges space over time. One explanation for this was that time was seen to be associated with change, karma and death whereas space was eternal and immutable (Baumer 1991).

While space has been understood to be either finite or infinite, such a problem does not seem to arise with matter, although both space and matter share the common quality of extension. Unlike space, a fundamental property of matter is its finitude. Matter is extended and finite. There is no object which has infinite matter. In other words, we could have empty space extending for infinity but no object that can extend for infinity. This is quite interesting because there seems to be some principle associated with matter which denies this infinite extensionality. This principle could be that of energy and a belief that we cannot (as finite beings perhaps?) possess infinite energy.

But this issue about extension has to be rethought in the context of quantum theory which claims that objects which are localised actually show wavelike characteristics of theoretically infinite extension. How to interpret matter in terms of its infinite extension is a problem that is a challenge to traditional philosophy.

Along with matter's property of being extended, there are other properties such as penetrability. We believe that space is completely penetrable. The space around us does not offer any impediment to motion; does not resist the movement of objects (matter) through it. It does not deform objects that move through it. In effect, it does not do anything to objects either residing in it or moving through it. Space is not only neutral to matter; it seems indifferent to it. (This indifference has been extrapolated to argue that it is indeed possible to consider the world without any matter but it is impossible to imagine the world with no space. This was the gist of Kant's argument. Contrast this with the opposite (Greek) view that there could be nothing called empty space or vacuum. Without matter there was no space.)

On the other hand, matter is impenetrable unlike space. This has to be qualified but impenetrability indeed suggests a characteristic of matter. Objects are impenetrable to other objects. We cannot walk through a wall. But what about liquids? An object can penetrate through a liquid, so can we claim that all matter has the property of impenetrability? Or consider the case of gas. A gaseous medium is made of molecules which have some matter and yet objects go through a gaseous medium. Paradoxically, the answer to the penetrability in liquids and gases can be explained by the penetrability of space and the existence of space 'within' matter. Liquids are made of matter with appreciable space between them. So when light is passed through a liquid it penetrates through because photons (which are sufficiently 'small') go through the empty space between the molecules of the liquid. While we can understand penetrability loosely in this sense both for liquids and gases, this is only one kind of penetrability. We can also have a big object penetrate through water; in this case, the object is not moving through the space between water molecules because the object is much bigger than the space between molecules. In this case penetrability occurs by displacing the liquid in the path of the moving object. This is similar to a bullet making a path through a solid piece of wood, for example. What this characteristic of penetrability shows is the inherent relation between the ideas of space and matter.

Space is essential to matter in a fundamental sense. If we accept the scientific theory of matter as being made up of atoms, then we are acknowledging that between bits of matter there is empty space. In an atom, the pieces of matter are the nucleus and the electrons. The total region occupied by the atom is that of these pieces of matter and of empty space between these pieces. One could say, as has been said before, that there is nothing called space more than saying that there is no matter at those points where we think space exists. This also implies, following Leibniz, that space is nothing but a network of relations between objects and as a relation it has no ontological status, unlike objects.

There is an intrinsic relation between space, matter and motion. In our common way of understanding motion, we recognize that without emptiness between objects, no object will be able to move. We also know that emptiness alone is not a guarantee for motion. Now if we believe that the emptiness around us is what we call space, then objects move in space and it is the penetrability property of space that allows the object to move from one point to another. Space does not offer resistance to motion; although objects may offer such resistance!

Identity

Space has another important role to play in the context of objects. We know what an object is only by distinguishing it from other objects. In general, we distinguish objects because there is empty space between them. When we keep an object in the background of space we can see the boundaries of the object clearly. This tells us what the object looks like and gives us some identity criteria for the object. Consider a piece of wood when placed in empty space. We can identify this piece of wood for what it is because of its contrast with space. Imagine placing this piece in a background which is only wood with no space to distinguish this piece from matter which surrounds it – in this case there is no way of recognising the identity of the piece. One may reverse this argument and say the same thing about objects – namely, objects give us a criterion of identity for space. When we ask what space is, we tend to first say that it is something where there is no-thing, no objects, no matter. So we can say that without objects there is no idea of space and it is the existence of objects and matter which gives us a definition of space. This is exactly the view of the relationists about space who argued that there is nothing called space; what we call as space is nothing more than the relations that exist between objects.

Change

Space is changeless. That is, there is no quality of space that changes

from one point to another (although this will not be so if we accept the curvature of space). The space around me here seems to be of the same 'kind' as the space in some other part of the world and perhaps the universe. There is no distinguishing characteristic that would allow us to say 'Ah! *This* is the space in Manipal' as against saying '*This* is the space in Delhi'. Also, the quality of this space does not change with change in weather, time and so on.

In the case of matter it seems to be, at the first instance, quite different. Consider an object – this is not the same as considering matter but we shall begin with this. There are many qualities that change in an object, including what we call its mass. But there is also an intriguing aspect to this change which has for long been observed: mass is conserved. This has been phrased in different ways, including saying that matter is conserved. Conservation of mass or matter implies that mass is neither created nor destroyed in the sense that in a process if an object loses some mass this mass is taken up by another object. Mass conservation has been replaced by energy conservation after the advent of relativity theory, since mass and energy are seen to be 'equivalent'. Thus, there seems to be some common characteristic of changelessness both in the case of space and matter.

Space is indestructible. Whatever you do to space, it doesn't seem to get affected. Even if an atom bomb explodes at a particular point, every bit of matter may get annihilated but it seems as if the 'space' remains untouched. (This should make us wonder whether space really exists!) Matter is not indestructible; we can annihilate matter. But the equivalence of mass and energy makes this a more complex issue. When matter gets annihilated or destructed, it gets converted to energy. But this statement is also not very precise. For example, in matter-antimatter annihilation, two particles with some mass collide and become a burst of energy. In the classical picture, mass/matter is indeed destroyed but in the modern, relativistic picture one can argue that mass has been converted into another equivalent state, namely, energy. Thus, the destruction of matter is also not a simple issue.

Space has been understood as a substratum for physical processes. This view has been held by a range of philosophies, including modern science. Space is necessary for events to take place in just as objects are *in* space. The substratum view is also shared by some philosophical positions on matter, which says that matter is the substratum on which all the properties of an object reside. In the substratum view, both space and matter are the most fundamental ground and they themselves do not reside in anything else.

There is another equivalent sense of substratum, one that can be seen in Kant's formulation of space. After 'proving' the existence of absolute space, Kant was led to the view that questions about the existence of space were fundamentally mistaken. The discussion about the nature and existence of space was influenced by the ways in which the existence of objects was addressed. That is, questions about the existence of space were framed in a manner similar to questions about existence of a thing, say a chair. Kant realised that this was the wrong way to go about it. His idea of space made a radical departure in the method of enquiry concerning space. The first point was that space was not like an object whose existence could be discovered by empirical methods. Space was not an empirical notion. The very idea of referring to something, to an object, presupposes the existence of space. Secondly, it is not possible to perceive without the notion of space. It is therefore necessary for perception to be possible. In this context, Kant argues that we cannot imagine a state of no-space although we can well imagine that there are no objects. Thirdly, unlike objects, space cannot be differentiated into 'kinds' such as chairs and tables. There is only one space.

The basic point is this: without space and time, sense perception is not possible. We cannot imagine space in our minds as we imagine objects. Space is not an object of perception. It is a mode of perceiving objects. Kant's philosophy of space (and time), although under attack after the discovery of non-Euclidean geometry, was (and remains) influential in philosophy and psychology.

Scientific ideas of space and matter

The scientific response to the question of matter has drastically altered the contours of this debate (Jammer 1966). One of the defining concepts of matter discussed earlier is extension. Interestingly, extension is a spatial idea; it implies the existence of the extended object in a region of space or at least as occupying a region of space. The common property of matter and extension led to some schools equating space and matter. In the early Greek tradition, it was argued that an object had the qualities of magnitude, shape, resistance and weight. Magnitude and shape were seen as geometrical properties and resistance and weight as physical properties. It was Buridan in the 14th century who formulated the important principle that 'quantity' of matter determines resistance. Thus, he defined mass as the quantity of matter. This mass is real and is not a geometrical property.

Kepler followed up by formulating inertia as resistance to motion. What characterises matter of an object is its resistance to motion. Objects do not move because matter has inertia. Kepler had an endearing phrase for inertia: 'plumpness of matter'. Newton clarified these issues clearly by defining mass as the 'quantity of matter' and momentum as the 'quantity of motion'. Newton's first law was actually about the innate power of resistance that is present in matter. Thus, for Newton, inertia was a 'force of inactivity' and this force is present in a body all the time. Matter, for Newton, was characterised in terms of these properties: extension, inpenetrability, mobility and inertia. After Newton, physical bodies began to be described in terms of mass as against matter. But there was a catch in postulating the property of inertia. Newton thought he needed the existence of absolute space to be able to distinguish 'real' motion as against rest and thus started a controversy over absolute space that went on for centuries.

Newton's second law gave a relation between force and mass. It was up to Euler to offer an understanding of matter and mass not in terms of inertia but in terms of a ratio – as the ratio of force and

acceleration. His formulation of mass meant that it was not necessary to understand mass only in terms of volume (i.e. as density multiplied by volume) but in terms of force. Along with Maxwell, Euler argued that force was the primary entity and not mass. Developing on this, Ostwald, around 1900, claimed that it was energy that was basic and not mass or force. Thus, mass should be defined in terms of energy.

The Newtonian formulation of mass gave rise to three types of mass. One is the inertial mass, the mass that is a measure of inertia or resistance of a body. Second is the passive gravitational mass and the third is the active gravitational mass. These two masses occur in Newton's gravitational law and is a measure of the gravitational force acting on a mass and the gravitational force caused by a mass. Theoretically, there is no reason to suppose that these masses all have to be the same although empirically and from Newton's third law we can conclude that these masses are at the least proportional to each other.

Our ideas of mass in modern physics have their origins not only in Euler and Ostwald's formulations but also in the attempt to find the electromagnetic origin of mass. The most famous proponent of this attempt was Abraham, who on the basis of Kaufmann's experiments, claimed that the inertia of an electron originates in an electromagnetic field. This implies that the mass of the electron must be understood as being purely electromagnetic in nature. Echoing this, Poincare too suggested that there was nothing called mass.

Poynting extended this to the case of fields. He began by arguing that energy doesn't need matter as a medium but has its own independent existence. Thus, he saw the electromagnetic field as a 'fluid endowed with inertia'. Using electromagnetic theory and conservation of momentum he showed that the mass of a field must be proportional to the ratio of energy and velocity of light squared – a formula that is analogous to Einstein's famous mass-energy formula but unlike Einstein he could not make the 'right' interpretation. (Einstein's famous result of mass-energy equivalence is in the paper with the title 'Does the inertia of a body depend upon its energy

content?'. His argument in this paper was that if a body gives off some energy in radiation, then its mass must decrease by the amount E divided by c squared.)

Einstein's theories of special and general relativity describe our contemporary, scientific understanding of the nature and existence of space, and also the nature of matter to some extent. The special theory of relativity introduced some basic changes in the way we understand space. Firstly, it rejected the existence of ether, a view that was held by some prominent scientists including Lorentz. What was central to the special theory was that there are only events which are situated in space and time. Absolute space was rejected. The postulation of the constant speed of light (c), thereby violating the Galilean velocity addition rule for light, implied a structure of spacetime that was radically different from Newton's. Fundamental principles defining the nature of objects and motion were overthrown because basic measures such as length, time and mass were not absolute to a given object. They varied depending on the velocity of the frame of reference. Although space was flat, it was not Euclidean but Minkowskian; this was essentially a consequence of looking at the continuum of spacetime instead of separate entities called space and time. The most important invariance in this theory is that of intervals instead of spatial distance.

The general theory implied a much more radical understanding of our ideas of space. This theory was basically concerned with gravity. Newton described gravity in terms of the law of gravity but did not attempt to explain the cause of gravity. General theory of relativity explains gravity – it says that gravity is caused by the non-Euclidean structure of spacetime. (Historically, it was Riemann who actually pointed to the importance of matter in the structure of space. But his ideas were thought to be too speculative.) According to Einstein's general theory, the presence of mass makes space curved; gravitation is caused by such curvature. Thus, contrary to all traditional wisdom, gravitation was no longer to be seen as a force. It is nothing but the spacetime curvature; as Nerlich (1994b) has it, gravitation is the

shape of spacetime. In one sense this takes us back to the Aristotelian view of the causal efficacy of space. For Aristotle, space was the cause of motion. What was troubling about that view was the ability of space to act upon things but the inability of things to act upon space. Einstein's theory makes a 'causal' connection between matter and non-matter, between objects and space. In doing this, there is an ontological commitment to an entity called spacetime. After Faraday and Maxwell, it is only fields that represent reality. Thus fields now become the fundamental concepts. There is also nothing called an empty space, because there is no region of space that is empty of a field.

Some of the earlier theories about space specified some qualities of space such as its infinite extension, penetrability and so on. The problem was that there seemed to be no sensible measures of space. This seemed to be the dominant view in most theories other than in some Indian philosophical traditions that suggested space could be sensed through sound. Einstein's theory now describes other properties of spacetime that can in principle be detected. The talk of symmetries of spacetime and observable consequences of it – for example, conservation laws – further add to the belief in the existence and detection of spacetime, and the intriguing relation between spacetime and matter/energy.

The General theory of relativity captures one interesting relation between space and matter. This theory entails a geometric nature of gravity. In particular, it postulates a relation between the spacetime manifold and mass, as given in Einstein's equation of general relativity. Schwarzchild equation suggested that the 'rate at which the metric deviates from flatness is interpreted as mass' (Jammer 1961). The curvature of space is actually related to the presence of mass and is indicative of the measure of mass. What is important to note here is that mass is to be interpreted and inferred in ways that are different from the classical traditions that described mass in terms of extension, inertia etc.

Around the same time, the postulation of anti-particles by Dirac's

theory meant that we had the idea of matter and anti-matter, which had the startling property that if they came together they would annihilate. Concomitantly, a burst of energy could spontaneously create two particles whose masses would carry the energy content of the initial energy. The problem of photons which have 'zero' mass leads to further problems of interpreting mass and, more significantly, the nature of an object. (Quantum objects in general have posed a challenge to standard metaphysics of objects.) Thus, not only was physics turned upside down by these new ideas but also the very ideas of space and matter.

As we saw earlier in the chapter, existence is not restricted to physical entities alone. Abstract entities could also be said to exist. Non-material entities like the mind and mathematical entities have as strong a claim to existence as material objects. The richly populated domain of abstract objects is an illustration of the kinds of entities that could be part of this world and these entities challenge the importance of matter as the marker of existence. This is a particularly important problem for science for this more than any other discipline invokes the world of abstract entities. Without making a commitment to their existence, modern science is not possible.

In such a scenario, what happens to the issue of matter? Is matter immaterial to science? Yes, if we understand matter in the traditional and sometimes commonsensical way. Science has constantly modified the concept of mass. Consider the trajectory of this idea in physics: from microscopic matter, to atomic, and finally to vacuum. As part of this growing narrative, mass has been related to charge, electromagnetic field and finally energy itself, as expressed in Einstein's famous equation. Capek (1961) writes, 'It is hardly surprising that the frustrated physicists began to realize that the solid particle was a mirage of their imaginations.'

Einstein's query 'Could we not reject the concept of matter and build a pure field physics,' is answered by him by saying that the 'field is not only real ... but is the fundamental reality of which

matter is only a particularly 'concentrated condition" (Athearn 1950). The more complex narratives on mass and matter do lead us to look at these notions with a fresh perspective. For example, the distinction of inertial mass and gravitational mass, the variation of mass with velocity as in the theory of relativity and the meaning of 'zero mass which photons apparently 'possess', should all be seen as consequences of the critical and creative understanding of reality by science.

The confusion engendered by quantum mechanics, as far as these 'classical' ideas are concerned, has further 'confused' the nature of matter. Particles, which also exhibit the properties of waves, cannot be incorporated into the world of classical ontology. The very meaning of 'existence' is under question when faced with the picture of particle-antiparticle annihilation (and their creation from vacuum). Thus, it is not surprising that Graves (1971) remarks, 'In the centuries that have elapsed between Plato's time and Wheeler's, the semantics and syntax of such concepts as "space" and "matter" have changed so radically that they have nothing in common but the names of the concepts (or rather their supposed translational equivalents).'

Scientific Realism – The Reality of Unobservables

I have mentioned how ideas such as mass, space, time and numbers are taken as real by science. While these are essential for physics, countless other such entities are needed for other disciplines such as chemistry and biology. The reality of atoms has been at the centre of human imagination for ages. The Indian philosophical traditions described a complex theory of atoms. Kānāda is the first philosopher to describe atomic entities but as we saw in the above section all other philosophical schools drew upon the idea of atom. Early Greeks, most notably Democritus, also described atomic entities. Now, one might ask, what do these descriptions of atoms have in common with the scientific understanding of atoms? Were all these people talking about the same atom?

This question has led to a long debate on incommensurability in scientific theories but that is a specific question that is of interest to philosophers of science. For our purposes we can argue that no two terms mean the same thing anyway – an atom for a student is different from one for a chemist, which is different from one for a nuclear physicist, which in turn is different from the view of a particle physicist. The point is not whether the exact same thing is referred to by the word 'atom' but whether there is a common conceptual space that is shared by all these different uses of the word 'atom'. In this spirit, ancient theories of atomism share many important characteristics with present day theories of the atom.

The point of this example of the atom is to illustrate science's constant search for newer levels of reality. Interestingly, the ancient atomic theories were also doing something similar when they talked about the atom because after all they were all aware that atoms could not be 'seen'. Philosophers also discussed in great detail whether some other unobservables like 'God' and mathematical entities could be perceived. To make sense of the possibility of knowing about things which we cannot observe ordinarily, philosophers sometimes invoked other senses or higher order senses. For example, the Nyāya school held that one could have an extraordinary perception of universals (to support the claim that when we see a cow we also 'see' the universal (or the essence) associated with the cow, namely, cowhood). Another way of responding to this possibility was to claim that one could 'experience' these unobservables – one could 'experience' God even though we may not see Her like we see trees. A mathematician like Cantor believed that one can 'see' sets as clearly as one sees objects although sets are mathematical objects which are usually understood to be abstract entities.

Science has an enduring relationship with unobservables. In fact, I would argue that its relation with unobservables is perhaps the most important aspect of science. This discourse on unobservables – describing a list of unobservables, knowing how to access them and how to manipulate them – is unique to science. No other

human activity comes close to science in opening up a new world of unobservable entities which are also seen to be real. And the way it does this is not through the method of extraordinary perception or invoking the notion of experience. It does this through the capacity of instrumental perception. Really, the greatest revolution in science is primarily that of learning to perceive through extremely varied types of instruments. This is also one aspect which almost no other activity comes close to.

Perception, for science, cannot be limited to direct perception. There is much in science which engages with the idea of indirect perception. Indirect perception also involves a large number of objects that can only be indirectly perceived. There are different types of unobservables in science: science talks about things which cannot be directly perceived like electrons, DNA, genes and so on; there are also theoretical entities, which arise only in particular theoretical contexts; there are mathematical entities; and relations as in laws of science. All these, which are the foundations of the theoretical enterprise, are not directly accessible to us.

In the philosophical tradition there is a very important distinction made between reality and appearance, and as a theme this dichotomy has been one of the most influential themes in philosophy. Our perceptual experience continuously emphasises the simple fact that what we see is not really what is there. This leads to our belief that there is always something underlying everything that we see and our perception is only the surface impression of the world. So to access the 'truth' of the world we need to go behind this appearance. One way to do respond to this problem of perception is to modify the organs of perception. The emphasis on instrumental perception ('seeing' through instruments) in science is a way of countering the limitations of our senses.

Instrumental Perception

There is nothing special about the idea of instrumental perception. After all, our physical senses are nothing but instruments: the visual

system is a complex instrument which includes the lenses of our eyes. Thus, one could say that even direct perception is mediated instrumentally; the only difference is that the instrument is hard-wired, attached, to the body. There is nothing obvious about direct perception. When I say that I see a cup in front of me there are many assumptions in this claim. Firstly, I believe that I am seeing the cup exactly as it 'really' is – that is, the cup has the shape, size and colour that I perceive. But even this assumption rests on many presuppositions since the perception of the cup is broken into many bits of information and is somehow put back together in our vision. (How this happens is a fascinating story, one that has led to serious research in fields like brain science and cognitive science.) So even seeing a cup in front of me is similar to seeing something through an instrument. The only major difference, and this is really the most significant one, is that an instrument's output is measured by an agent whereas when we see we are ourselves part of the machine.

As mentioned above, all our senses are limited in various ways. To discover the real nature of the world we need to find mechanisms that will help us overcome these limitations. The invention of a telescope helps us see objects that are far off; similarly the microscope helps us see things that are invisible to the eyes. A major project of science is to refine these instruments to make them more and more powerful as well as more and more accurate. This is the reason why instrumentation is such an important part of the project of science and people who manage to build such sophisticated instruments are as important as theoreticians who manage to have insights into the structure of the universe.

Today, we have instruments that can help us 'see' atoms; we can actually move atoms – or at least that is what the scientists tell us. We have the capacity to minutely map the structure of the human body, including a map of its genes. We have the capacity, through instrumentation, to build enormously complex chemical compounds. It is staggering to realize the enormous potential

of all this instrumentation. And in doing this science poses new philosophical challenges to its original project of describing and understanding the world.

One such challenge, and a major one at that, is to make sense of the world which instrumental perception opens out to us. By its very nature, it is possible that what we perceive through instruments may be an artefact of the instrument and not necessarily something present in the world. For example, if we hear some sound from a radio it could be from a radio station or some static in the atmosphere or it could merely be a problem in the radio circuitry. So we should have the capability to distinguish the information that is generated by the instrument (similar to noise) and that generated through its observation of something outside the instrument. Scientific observation is as much about fine tuning this distinction as it is about perceiving the unobservable world.

But we cannot really make sense of what we perceive through instruments without first having an interpretative framework. This framework is often called theory but in general it could be any broad framework which allows us to make sense of what we perceive through instruments. Consider this example: electrons were instrumentally discovered through interpreting how their trajectory changed under electric and magnetic fields. Although J. J. Thomson discovered this deflection by letting cathode rays fall on a phosphorescent patch, later experiments allowed one to take photographs of the trajectory of the particles so that one can see the curved trajectory of the particles. In this case, the experimenter looks at the photograph and from seeing the lines on it she manages to 'see' the path of the electron. When we (as non-scientists) look at the photograph we only see some lines on it but when the experimentalist sees the photograph she is looking to interpret these lines in a particular way. How she interprets it often depends on the theory she has. If she has a theory that electrons have charge and are deflected in an electric field, she can make sense of the way the lines curve. This allows her to deduce the properties of charge and mass of an electron through this interpretation.

This means that instrumental perception is primarily an inference. Philosophers of science have coined the term 'theory-laden observation' to emphasise this point that there are no naïve observations but only theory-laden ones. A strong implication of this view is that we only perceive what the theory allows us to perceive – in other words, the theory that we hold dictates what is perceivable through instruments. If we accept this view then the implication is that we cannot be sure that what we claim to perceive through instruments are actually out there in the world.

Another way of saying this is that we have no real confidence that we can independently access the unobservable world without the mediation of the instruments. Given the specialty of instrumentation and theory, there are very few people in the world who can actually 'read' instrumental output. To understand what is being recorded in an instrumental observation is really a super-specialised task which is not possible for most scientists themselves. In other words, we have to believe the words of a few people when they interpret observations from experiments. Contrary to an image of science where it seems that scientists get obvious results from experiments, it is often the case that the first inferences from an experiment are subjected to intense scrutiny and criticism. There is really nothing obvious in instrumental observation to the vast majority of non-scientists and scientists alike. Interpretation of instrumental observation is an art that has to be carefully cultivated.

One of the consequences of the theory-laden view is that one could interpret the same observation differently if one held a different theory. That is, scientists interpret a photograph as evidence for the existence of an electron only because they hold a particular theory of electromagnetism. If there was another theory that explained the photograph then the object whose presence is captured in the photograph could in principle be something else. One way by which science intuitively counters this possibility is by using different experiments to reach the same conclusion. If different experiments and observations, based on different theories, all lead to

similar conclusions about things in the world, then it increases the confidence that such things indeed exist in nature. Such attempts are an integral part of scientific practice but given the enormous complexity of instruments and experiments today, as well as the exorbitant costs, it is really not possible to find alternate experiments in every case. So there is much that is concluded from instrumental observation in today's world that we accept a little more easily than in the earlier years of science.

The significance of interpretation in experimental observation must not be discounted. Such interpretations are not only to discover the world of unobservables but they also have enormous effect on daily life. Medicinal technology is one important example. Our understanding of our body and of sickness and pathology is very much dictated by our belief in instrumental observation. Everything is interpreted and represented as visual objects in modern medicine. Pathology, which is necessary for diagnosis, is based on interpretation and again these observations in general are theory-laden. The state of modern medicine today is very similar to that of modern physics and chemistry in that dominant modes of understanding are entirely through interpretation of instrumental observations. While this may have its advantages it most definitely has its share of serious problems, particularly in the case of modern medicine.

The history of science is filled with examples where observations have been used to infer the existence of something which later turns out not to be true. So it is safer to be a little prudent when we claim that something surely exists based on certain instrumental observations – whether the claims are about quarks or about the functioning of the bodily organs. (One might think that there is very little interpretation of X-rays. When we look at an X-ray of the lungs, we seem to be able to 'see' the lung clearly without any interpretation. But, alas, nothing is so simple! The story of X-rays is a fascinating story in itself (Pauwels 2006). But, all said and done, instrumental perception as well as the uncovering of the unobservables are an essential part of science. These characteristics also distinguish science

from almost all other activities and disciplines including astrology, social sciences and so on. This perspective that is at the heart of science is also intrinsically linked to the larger project of technology. All these are driven by a particular view of reality and paradoxically, in so doing, create a much more complex narrative of reality than is done even in an imaginative activity like literature. I will conclude this chapter by exploring this paradoxical relation between science and reality by contrasting it with literature's engagement with reality.

Literary Reality and Scientific Fiction

Over centuries, both science and literature have been involved in creating particular images for themselves. Foremost has been the attempt by science to appropriate the notions of reality, truth and knowledge within its domain and activities. Literature has been a silent partner in this act of appropriation because such an appropriation suits its own image making. Even as much as the discourse of science constructed itself consciously in opposition to the discourse of literature and art, literature too found ways to consciously distance itself from scientific discourse, which included not only differences in their conceptual worlds but also in the way their texts were presented. They are both parties to the establishment of the common perception that science is intrinsically related to the ideas of truth, reality and knowledge and literature with fiction, myth and imagination. Associated with these categories are various others such as subjectivity (literature) and objectivity (science).

If we critically analyse these claims, we discover that these images about science and literature mask the 'true' nature of both these activities. Not only is literature in a surreptitious relation, an illicit affair, with reality and therefore knowledge but so also is science in such a relation with fiction and subjective imagination. So the practices of both literature and science allow us to challenge commonly held presuppositions about them. The consequence of such unmasking is to remind us that the ideas of reality and knowledge are much indebted to fictional imagination and fiction

itself blossoms from the hard ground of reality and knowledge.

Novitz (1987) argues that literature is an important source of knowledge about the real world. Moreover, literature provides knowledge which is 'richer and more varied' than the empirical sciences. Primarily, the question about reality has to do with our description and understanding of the real world, and having the means to compare our description with the world. A scientific work makes an explicit reference to particular physical objects, events or phenomena. But so do literary works. The influential writer on aesthetics, Monroe Beardsley (1958), notes that 'by their nature literary works have an essential and unavoidable reference to reality.' The reality that literary works refer to is not only the world of the individual and society but also that of the natural world and our relationship with it. Furthermore, just as we have a notion of scientific reality so also do we have the idea of literary reality. For Novitz, literary reality is the 'world in which we live', meaning therefore that there is really no distinction between our 'real' world and the world of the literary. For de Man (1982), the literary reality is the 'phenomenal world', the world of experiences.

There is no knowledge system which does not possess elements of the literary or the fictional imagination. I will consider this claim with respect to two of the most influential knowledge systems, which are the exemplars of what we would call as knowledge, namely, science and mathematics. In what follows we will see how these bodies of knowledge are necessarily related to fiction.

The fictional in science and mathematics: how real should science be?

There is much that is in the nature of the fictional in science and mathematics. The association of fiction with science may be more obvious and clearer to understand. This is because science is a discourse about the world and the world functions as the final arbiter of its claims. This is the way in which reality intrudes into the scientific discourse. However, its essential relation to the fictional

imagination is obvious since its narratives about the world are only that – possible stories about the world out of which some might be accepted as the 'correct' one. The stories that are not accepted (say, theories that are discarded) are on par with fictions.

In illuminating the use of the fictional in science and mathematics, I will discuss four 'objects' that are essential to modern science and which can be, depending on one's philosophical position, fictional.

Space and time are the foundational entities upon which modern science rests. Without believing in the existence of the entities called space and time, it would have been impossible to construct science as we know it . The most basic description of motion begins with the idea of change against a background of space and time. In various ways, science betrays an ontological commitment to these two entities. However, the 'existential' status of both these entities is not obvious. As discussed earlier in this chapter, there have been many views on the nature of space. In particular, the relational theory of space argues that there is nothing called space but only objects in the world since space is nothing more than a relation between these objects. There are also other arguments for claiming that an entity such as space cannot exist. One of them has to do with the observation that space is not accessible to us through our senses – we cannot see, touch, hear, taste or smell space. So what guarantees our belief in the existence of space? Space could be a fiction, a fiction that is essential to the real discourse of science.

Newton believed in the existence of what he called absolute space. Such a characterisation of space was thought to be essential for a foundation of his laws of motion, particularly the First Law. Newton also believed that he had experimental support to prove the existence of absolute space. What is interesting to note is that it took over two hundred years to show that absolute space was a fiction yet in those years important developments in science took place even with this fictional entity as an important element of the scientific narrative. There are many other such examples, including the well known one of the existence of ether which was finally showed to be

non-existent. In other words, a large body of scientific knowledge was created based on the belief in the existence of entities that were later recognised to be non-existent (and therefore fictional?). What is important for our consideration is this possibility of creating a wide body of accepted knowledge which is in many ways based upon fictional entities.

Time is also possibly fictional, in the sense that there is a reasonable argument to show that the entity that we call time does not really exist. While philosophical arguments for this can be found, it is interesting to note that even within scientific theories such a possibility is present. Godel, arguably the greatest logician of the twentieth century, constructed a consistent solution to Einstein's equations of general relativity in which time did not have existence. This solution, called Godel's universe, implies that it is possible to have a consistent theory of the world without time as a 'real' entity. However, without belief in the existence of time, science as we know it would not be possible. Even the most basic analysis of movement and speed is based on beliefs about the existence of space and time.

Mathematics offers another set of interesting examples that challenge our naïve view of fiction and its relation to knowledge. I will only discuss two simple examples with the added comment that these examples are not really special but embody a process that is common to the discourse of mathematics. The first is the example of infinity. Infinity as a concept had been an integral part of all world philosophical traditions. However, the mathematical approach to infinity differed in a fundamental sense from the metaphysical idea of infinity. In the long history of this idea, we can see various approaches to the reality of infinity – while some held that infinity was 'real', at least in the sense of the reality of the divine, others believed that infinity was just a concept and could not have anything to do with reality. Debates on how finite human beings could ever grasp infinity were common in the philosophical traditions. However, in the nineteenth century the mathematician Cantor gave a new formulation of infinity. His theory of mathematical infinity engages

in a profound sense with the question of the reality of infinity. Cantor 'showed' that infinity was not actually a nebulous domain, something which did not distinguish between one infinite and another but was structured like numbers. The point is that while numbers like 1 and 2 can be distinguished there were no such 'numbers' related to infinity which would in principle help us understand the structure of this domain. Cantor's formulation of the transfinite cardinals was exactly this: to exhibit a complex structure among transfinite numbers thereby allowing us to understand how one infinity can be 'greater' than another. This structure of the domain of infinity makes it more real and the language of the transfinite numbers constantly betrays a realistic commitment to them. However, the idea of infinity continues to remain a vague idea in the human imagination and is fundamentally related to the fictional imagination. But, more importantly in the context of our discussion, the idea of infinity is very important for science.

This question about the reality of infinity is similar to that of the reality of numbers. While there are influential philosophers who believe that mathematical entities inhabit a Platonic world (a world which is outside space and time!) there are others who believe that these are convenient fictional entities. Without entering into this debate, let me only make the comment that what is interesting in this debate is the possibility of fictional entities collaborating together to create the discipline of mathematics, a discipline which to us is a paradigm of knowledge and truth. While one may respond by saying that mathematical truths are not the truths of the world and hence the question of reality is indifferent to mathematics, we should note that this would be too hasty a conclusion. For, as is well known, the origin of modern science has been traced to the essential use of mathematics in the sciences. Famous scientists such as Galileo, Newton and Einstein have all voiced the belief that nature is written in the language of mathematics. Given that there is no modern science without this hovering presence of mathematics, we need to understand how knowledge about the real world is possible by using

entities that in no conceivable sense are 'real'. In fact, fictionalism is an important theory in the philosophy of mathematics, a view that understands mathematical entities as fictional entities. Even with all the attendant problems of this view, the very fact that such a view is possible must make us wonder about the relation between the fictional and the real, between the imagined and the truth, between stories and knowledge.

Yet, science is able to continue its activities, make new truth claims about the world, without worrying that its foundations are filled with the elements of the fictional and the unreal. It is this pragmatic nonchalance about the real and the fictional that is special to science.

Imaginary and the real

An interesting insight into the nature of fiction and the essential significance it has for science can be found in the use of imaginary numbers in science. Imaginary numbers are those numbers which are contrasted with 'real' numbers. They first arose in trying to find square roots of expressions whose squares were negative numbers. Since the square of any real number (positive or negative) has to be positive it meant that there could be no real numbers which would be equal to a square root of a negative number. However, the postulation of imaginary numbers meant that a number, i, was defined so as to have the property that its square is -1. Given this number, we can construct a new set of numbers called complex numbers which are in general of the form $x + iy$, where x and y are real numbers and i is the imaginary number.

There are some very interesting properties of complex numbers, one of which is their essential role in describing the real world. There is an important sense in which numbers and the world share the appendage 'real' and this is the belief that real numbers have something to do with the expression of the reality of the world. And similarly for the imaginary number – an imaginary number, it is believed, by itself does not correspond to anything in the world. There

is thus a naïve but powerful association between the imaginariness of the imaginary number and a fictional world. In fact, the belief that imaginary numbers do not represent real things is such an enmeshed belief in the sciences that when quantum mechanics was first developed there was a serious problem in interpreting the wave function. The wave function was a purely imaginary term and thus could not really represent a physical entity. No observable (therefore physical, real) quantity in quantum systems can be purely imaginary. What is intriguing in this view is the fact that real numbers are themselves not real in any sense of the physical reality of the world, yet we are able to make a distinction between real and imaginary numbers as far as their reference to the world is concerned!

Complex numbers, which are the combination of real and imaginary numbers, have become indispensable to the sciences. In fact, they not only make the mathematics of physics and other sciences easier but they are also essential to the mathematical description of the real world. There is a simple lesson here: to talk about the real it is *necessary* to invoke the world of the imaginary.

I believe that this idea of imaginary numbers leads to a profound insight about the nature of the real and imaginary. It is that the imaginary and the fictional are not contradictory to the real. The really real world is an intertwined mixture of the real and the imaginary and the fictional. And as we have seen in this chapter, the power of scientific imagination, the power to create the unobservable worlds of science, rests on a dynamic relation between truth and fiction.

References and Further Reading

Beardsley, M. 1958. *Aesthetics: Problems in the Philosophy of Criticism.* New York: Harcourt, Brace and Company.

Keith, A. B. 1977. *Indian Logic and Atomism.* New Delhi: Oriental Books Reprint Corporation.

Pauwels, L. (Ed). 2006. *Visual Cultures of Science.* Hanover: Dartmouth College Press.

On ideas of matter and space, see:

Baumer, B. 1991. "From guha to akasa: the mystical cave in the Vedic and Saiva traditions". In Vatsyayan (Ed.) *Concepts of Space: Ancient and Modern.*

Bhattacharya, N. N. 1999. *Jain Philosophy.* New Delhi: Munshiram Manoharlal.

Brooke, J. H. 1995. *Thinking about Matter: Studies in the History of Chemical Philosophy.* Aldershot: Variorum.

Kramrisch, S. 1991. "Space in Indian cosmogony and in architecture." In Vatsyayan (Ed.) *Concepts of Space: Ancient and Modern.*

Capek. 1961. *The Philosophical Impact of Contemporary Physics.* Princeton: Van Nostrand.

Cassirer, E. 1953. *Substance and Function and Einstein's Theory of Relativity.* New York: Dover.

Graves, J. C. 1971. *The Conceptual Foundations of Contemporary Relativity Theory.* Cambridge, MA: MIT Press.

For a very readable account of the histories of space and mass, see:

Jammer, Max. 1954. *Concepts of Space.* Cambridge: Harvard University Press.

Jammer, Max. 1961. *Concepts of Mass.* Cambridge: Harvard University Press.

Lowe, E. J. 1998. *The Possibility of Metaphysics.* Oxford: Clarendon Press.

Moore, A. W. 1990. *The Infinite*, London: Routledge.

Nerlich, G. 1994a. *What Spacetime Explains.* Cambridge: Cambridge University Press.

Nerlich, G. 1994b. Second edition. *The Shape of Space.* Cambridge: Cambridge University Press.

Novitz, David. 1987. *Knowledge, Fiction and Imagination.* Philadelphia: Temple University Press.

Sarukkai, Sundar. 2002. *Translating the World: Science and Language.* Lanham: University Press of America.

Sarukkai, Sundar. 2007. "Literary Reality and Scientific Fiction", *JJCL* 44.

Winter, I.J. 1991. "Reading concepts of space from ancient Mesopotamian monuments". In Vatsyayan (Ed.) *Concepts of Space: Ancient and Modern.*

A recent and interesting philosophical treatment of fiction is:

Sainsbury, Mark. 2010. *Fiction and Fictionalism.* London: Routledge.

V

Science and Knowledge

Science has a special relationship with knowledge and truth. In fact, it is the standard model for knowledge and truth. Various disciplines try and mimic certain aspects of the natural sciences in order to generate the kind of knowledge that is exemplified by scientific knowledge. In the public imagination of science, the idea of truth is strongly associated with it. Scientific truths are understood to be literally true – meaning that they are not open to interpretations, not open to individual likes and dislikes, and so on. Moreover, the stories about science are all about discovering truths of nature. Even when scientists talk about exotic entities like quarks and genes, they are generally accepted as being true. Most importantly, we do not believe that the public or the non-scientific community will decide on what is true and what is not within science. That is, although we might recognize that some truths in science get falsified and replaced by new ones, we leave this judgement to the scientists alone.

To understand what is so special to scientific knowledge and truth in science we have to enquire into the nature of these terms. Philosophers and social scientists have for long debated extensively on these topics. In recent times, there have been serious challenges to traditional views of knowledge and truth, some of which are relevant to the claims of scientific knowledge. I will begin with a short introduction to the nature of knowledge, including Indian approaches to knowledge, and then summarize a few salient points of scientific knowledge.

Beliefs, Justification and Knowledge

We may have many beliefs but only some of them are accepted as knowledge. We may have beliefs which we are sure is true but may not be able to convince others about their truthfulness. To say that we know something is indeed a complex claim depending on various factors. What is knowledge? What are the criteria for accepting some beliefs as true? What is the relation between truth and knowledge? What is the structure by which we can assert that we have knowledge of something?

These and related questions are dealt with in a branch of philosophy called epistemology. Before I discuss what is special to scientific knowledge, I will give a brief overview of epistemology, focusing primarily on the structure of knowledge systems.

We hold various kinds of beliefs. We may have many reasons for holding these beliefs. Perception is one common source for beliefs. But seeing something and *knowing* that thing (or something about that thing) are quite different processes. Seeing itself is a complex of many elements: the perceiver, the object (and the field of perception) that is perceived, the sensory experience of perceiving and the relation between the object and the perceiving subject. Thus while we take seeing to be matter-of-fact, a philosophical analysis of it raises some fundamental questions.

Typically, we move from perceiving something to believing something about that thing. Belief in itself is not necessarily true, for we may hold false beliefs. To have knowledge is at the least to have true belief. But what if this true belief is a lucky guess? It is not enough to have true belief if there are no reasons to hold this belief. What distinguishes knowledge from merely believing, even if it is true belief, is to have some justification for believing it to be so. Thus, as a starting point, we may define knowledge as justified true belief.

There are different sources of justification. In the standard account, there are five sources: perception, memory, consciousness, reason and testimony (Audi 1998). At the most fundamental level perception gives us justification for believing in what we perceive. But as is well known perception doesn't guarantee certainty as we may see an illusion or be mistaken about what we see. From perception we may have to infer the true state of affairs. The example of mistaking a rope for a snake or seeing a bent stick when it is dipped in water are examples which show that what we see is not what is always there.

Memory is also an important source of justification and knowledge. To understand what we perceive we draw upon memory. There are two modes of memory: remembering and recalling. Beliefs grounded in memory are called as *memory beliefs*. These beliefs are at least partially produced by events that occurred in the past. Memory plays a very important role in justification. It may in itself not generate knowledge but helps to retain belief and knowledge. Thus, memory is not a 'basic source' of knowledge; we need other mechanisms to generate belief. But memory is a basic source of justification. It justifies many of the beliefs we hold and this justification does not consist only in remembering an event but also in remembering various kinds of propositions. Memory and perception function similarly in some aspects. They are both necessary for justification of many of our beliefs. But perception may be more fundamental because it also functions as a source of beliefs. Perception is in some sense a source for material that becomes part of memory. But without memory our capacity for knowledge may not be possible in the way we have it now.

The third source of justification and knowledge is consciousness. One of the important elements of consciousness is introspection, meaning thereby 'attending to one's own consciousness.' Consciousness, including introspection, is a basic source of belief, justification and knowledge. There is also a profound difference between consciousness and the other sources such as perception and memory. This is due to the presence of *will*, which allows one to actively call upon rather than merely respond. This has led to some philosophers calling consciousness an *active faculty* and perception and memory as largely *reactive faculties*. An important difference between consciousness and perception is that perception allows us to

hold beliefs about the external world whereas introspection unravels the richness of the inner world. Both are necessary for knowledge.

Beliefs can arise and be grounded in perception, memory and consciousness as described above. But in our experiences we believe in certain truths that are not dependent on just these three elements. A common example is that of recognising relations such as taller and shorter, greater than and less than. These 'truths' are a product of reason and we grasp them intuitively. Truths like these are referred to as self-evident truths. They can be recognised in their immediacy and do not need support of evidence, inference or memory. Self-evident truths are necessary ones. Empirical propositions are synthetic in that these truths are knowable only through experience as against the use of reason alone.

There is yet another source along with the above four, namely, testimony. Most of what we learn, whether as students or as professionals, is learnt from others, from relying on teachers, authority figures and from books and journals. The first four sources are primarily sources which are based in the individual and the fifth, testimony, is a social source of justification and knowledge.

There are significant differences in the way knowledge is understood in Indian philosophy as compared to the Western tradition. In standard accounts of knowledge in Indian thought, knowledge itself is a mental process and knowing is a mental episode, characterised by its capacity to be 'truth-hitting'. For the Indian philosophers knowing is an experience that comes closest to the anecdotal experience of knowledge that led Archimedes to shout 'Eureka' as an expression of his awareness of having 'hit' the truth!

Indian theories of knowledge are called as *pramāna* theory. *Pramānas* are means of knowing. They are the valid 'instruments' of knowledge. *Pramāna* theory tells us how we come to have knowledge, namely, through different *pramānas*, the different means of valid knowing. In this view, there is a double-sided nature of *pramāna*, both as a means of knowing and as a cause for knowing. For example, to claim that we 'know' that an object is in front of us is to believe

in the truth of our perception. It is to say that perception is a valid means of knowing about the existence of an object. However, it is also true that I see an object in front of me only because I am able to perceive it and so in this sense my perception causes my being aware of the object. One can understand the *pramāna* theory, as Matilal does, as a philosophy of empiricism. The *pramāna* theory has also been described as a causal, reliabilist theory of knowledge.

Scientific Knowledge

With this general background on beliefs, justification and what constitutes knowledge, we can now ask what is it that makes scientific knowledge unique and different from other systems of knowledge.

Science is interested in a particular set of objects and events. It aims to describe, explain and predict the behaviour of these entities. These objects and events constitute what we normally call as things in nature and natural phenomena. As we saw in the previous chapter, in trying to understand the natural world science invokes a whole new set of entities other than the usual concrete objects, namely, abstract entities. They arise in mathematics and in theoretical expressions. So science necessarily needs a domain of abstract entities in order to describe, explain and predict the physical natural world.

Perception is a source of knowledge for science. Perception is the first source for scientific enquiry. As discussed in the previous chapter, instrumental perception is essential for science. From these forms of perception, beliefs are generated and then to become knowledge they have to be validated. In the traditional account of epistemology we saw that sources of justification and knowledge were perception, memory, consciousness, reason and testimony. We have already seen that in scientific knowledge the role of perception has been drastically altered. What about the other sources? Memory plays a role in scientific epistemology similar to what it does in other systems of knowledge.

Consciousness, like memory, has an ambiguous role to play in scientific knowledge. While we may grant that consciousness,

including introspective consciousness, is necessary for epistemology, it is not clear if it has any specific role in scientific knowledge that distinguishes it from its role in any other epistemological systems. The reason for this is again similar to the role of memory in scientific knowledge. Consciousness remains grounded in the subjective and validation of the subjective is a serious problem for science. Also, the issue of will – central to consciousness – makes consciousness a potential problem for science. In general, the problem for science with consciousness is the larger problem which science has with the human subject. Although science is a human creation, the human subject is seen, by science, as merely a passive agent who only faithfully reads, records and translates what it sees around it. In other words, the human *will* should have no role to play in the scientific discourse of the world.

Reason, on the other hand, is probably the most privileged source of scientific thought. Reason is manifested in diverse ways in scientific knowledge. An ideal image of science is that it is made equally of two parts: empirical and theoretical. These are not independent of each other but draw from one another. Nevertheless, there is one 'type' of reason that is privileged in science.: mathematical reason. Mathematical reason was the exemplar of reason for the Greeks and this has continued to influence the notion of reason in science. One reason for this is that mathematics embodies deductive reasoning and therefore offers a notion of certainty to reason. So in the context of scientific knowledge it is important to ask: how does mathematics contribute to scientific reason, creation of scientific beliefs and knowledge?

Finally, what is the role of testimony in scientific knowledge? Among all sources of belief, justification and knowledge, testimony might seem to play the least important role in science. One of the defining characteristics of science is the challenge that it poses to any authority. The only authority for science is the world-as-is. Humans are but agents who discover the ways of this world but do not contribute any of their own experiences, feelings or desires

to the story of this world. Thus, the scientific views of a scientist, however well established she may be, are always open to question and potential rebuttal. But this does not mean that there is no notion of testimony in scientific knowledge. Testimonial knowledge is essential in the pedagogy of science and also in professional activities of scientists such as in publications. Moreover, while individual ideas may be questioned, for most scientists foundational issues of science are still out of bounds for critique. In fact, there are many foundational assumptions of science which are accepted (largely through testimony) without thought by scientists.

What then is special to scientific knowledge? First and foremost, scientific knowledge is pragmatic in nature. It is interventionist in spirit and therefore, any statement is accepted as knowledge if something can be done using it. Nevertheless, there are some common concerns in a philosophical understanding of scientific knowledge and the scientific activity of producing knowledge. First, the notion of truth is extremely important. Scientific knowledge is about truths of the world; scientific processes generate these truths.

However, since every statement of science is open to challenge, scientific knowledge is inherently fallible. This means that every statement of knowledge and truth in science is potentially open to correction or even complete rejection. It is worthwhile noting that Nyāya holds a fallible theory of knowledge. Nyāya and science share, among other things, a commitment to realism, particularly realism of the world.

There are other important elements that are special to scientific knowledge. One is the idea of approximation, which makes possible a comparison between the world and the scientific narratives of it. Creation of new concepts is another special aspect of scientific knowledge. Scientific description of the world is most often unique because of the unique concepts that it creates. For example, while ordinary description of motion might only use ideas such as speed, science uses more refined concepts like velocity and acceleration.

Language and Knowledge: The Special Place of Mathematics in the Sciences

Knowledge may arise through many different means as discussed in the earlier section but finally all articulations of knowledge has to be converted to a text, to a medium which allows public communication of this knowledge. Unlike experiential traditions, like spirituality and mysticism, where truths of experiences are primarily experienced by the individual, scientific truths and knowledge should necessarily be part of a public domain. The way to do this is to convert insights of truth and knowledge into expressions of language. But in doing so, there has to be a guarantee that the truth does not get modified, diluted or distorted by the way language expresses them.

The birth of modern science can as well be traced to its suspicion with natural languages (like English and Kannada). Such languages were seen to be ambiguous, imprecise and leading to confusion in communication. They were also not seen as the most efficient language of nature. In the beginning of modern science, there were two different ways of responding to this problem. One way was to mathematise science and the other way was to change natural language so as to make it more precise and unambiguous. Galileo catalysed the first move and Newton was instrumental in doing the latter. Both these practices inform scientific use of language today. On the one hand, there is appreciable use of mathematics (even in disciplines like biology and chemistry, and in economics and now in management studies) and even where there is no such use, a natural language like English is itself made more 'sterile', impersonal, literal (as against metaphorical) and nominalised when used in scientific writing. In the remaining part of this chapter, I will address the very important question of the use of mathematics in the sciences. This is not only essential to making sense of what is special to science but it is also one that has influenced the nature of a wide variety of disciplines which aspire to be a science.

The 'unreasonable effectiveness' of mathematics

Some words and phrases are destined to capture the imagination and in so doing get widely used. As a consequence, they are also open to serious misunderstanding. 'Unreasonable effectiveness of mathematics' is one such phrase which is often invoked but little analysed or understood. This phrase was made famous by Eugene Wigner in the Richard Courant Lecture in Mathematical Sciences at New York University in 1959, which was subsequently published in the *Communications in Pure and Applied Mathematics* in 1960. I will begin with summarizing Wigner's arguments in order to understand exactly what he meant when he used the phrase 'unreasonable effectiveness', after which I will analyse what mathematics and mathematisation means, and then conclude with one explanation for the effectiveness of mathematics.

Wigner begins with a story of two friends, one of whom, a statistician, was working on population distribution. When the statistician explained the symbol π occurring in a particular distribution, the friend, who presumably was not a mathematician, thought it was a joke and said, 'surely the population has nothing to do with the circumference of a circle.' Wigner learns a lesson or two from this story. He first notes that mathematical concepts turn up unexpectedly thereby providing close descriptions of some phenomena. Secondly, he believes that because we do not know the reason why mathematics is so unexpectedly useful we will not be able to say with certainty whether a theory we hold true is uniquely appropriate to a phenomenon or not. With this as his starting point he analyses the usefulness of mathematics in the natural sciences and comments that this usefulness is mysterious and has 'no rational explanation' for it.

The significant use of mathematics in the sciences owes a great debt to the belief that the laws of nature are written in the language of mathematics, a statement attributed to Galileo and one which has been echoed for centuries after by figures such as Newton, Einstein and Feynman. Wigner too joins this chorus and begins by

correctly noting that only some mathematical concepts are used in the formulation of laws of nature and these concepts are not chosen arbitrarily. One of the elements contributing to the mystery of mathematics lies in the physicist stumbling upon a mathematical concept that best describes a phenomenon only to find that the mathematician has already developed that concept independently. As examples, Wigner cites complex numbers and functions, the appropriateness of which is especially manifested in the formulation of the complex Hilbert space which is so essential to quantum mechanics. The surprising (to the common sense) and necessary role of complex numbers and functions along with the idea of analytic functions is one example of the 'miracle' of mathematisation.

The important argument here is that mathematical concepts are not accidentally useful but are *necessary* in the sense that they are the 'correct language' of nature. Wigner offers three examples to illustrate this necessary relation. The first is that of Newton's law. Not only was this law based on 'scanty observations', it also contained the physically non-intuitive idea of the second derivative and yet exhibited an extremely high sense of accuracy. The second example is the matrix formulation of quantum mechanics. The miracle in this case, according to Wigner, lay in the fact that one could apply these matrix methods even in cases where Heisenberg's initial rules did not apply, as illustrated in the calculation of the lowest energy level of helium. The third example is that of quantum electrodynamics, particularly the theory of Lamb shift, a theory which again showed extremely high accuracy with experiment. From this, Wigner concludes that mathematical concepts, 'chosen for their manipulability', are not only appropriate but are also accurate formulation of the laws of nature. For him, these laws together with the laws of invariance are the foundation of the mathematical method in sciences. Finally, he considers the uniqueness of theories in physics and asks whether mathematics alone can help adjudicate which theories are essentially right. The problem here is that some theories which are known to be false also give 'amazingly accurate results'. The examples he gives of these 'false' theories are Bohr's early model of the atom, Ptolemy's epicycles and also the free-electron theory.

Wigner concludes by saying that the 'miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve.' I have no comments on whether we *deserve* this 'gift' or not but as for understanding it, we can at least make an honest try – and this many philosophers have done.

But what is mathematics?

Much of what Wigner says must perforce depend on what he means by mathematics. Wigner says little about what mathematics is but what he says is suggestive. Wigner writes, 'mathematics is the science of skillful operations with concepts and rules invented just for this purpose. The principal emphasis is on the invention of concepts.' This ability to create concepts takes the mathematician into unchartered realms to the point of being imaginatively 'reckless'. Further, there is a notion of generality, simplicity and beauty inherent in this creation.

Wigner, like many scientists, blissfully ignores some of the seminal contributions from philosophy to the understanding of mathematics. His view of mathematics, emphasising the importance of rules and the human creative element in creating concepts and rules, runs counter to some dominant views on mathematics. Although Wigner does not explicitly push this point further, it is clear that his understanding of mathematics as being rule-driven makes the effectiveness of it a much greater mystery. Namely, how is an activity of humans, driven as it is by rules we create and with human-centred ideas such as beauty, so well matched with the natural world? Wigner was right in his characterisation of mathematics even though his analysis of the question is questionable.It will be useful to briefly discuss the dominant views of mathematics before we consider the question of applicability. I will summarize five different views on the nature of mathematics. The divergence of these positions clearly suggests

that the mysteriousness of applicability has its origins in the 'mysteriousness' of mathematics itself.

Platonism: Let me first consider the realist view of mathematics. Realists about mathematics would believe that mathematical entities exist independently of humans just as trees and tables do. Platonism about mathematical entities is the dominant realist tradition. Platonists believe that mathematical entities have an existence independent of human minds. These entities inhabit a special world, the Platonic world. Platonism thus believes not only in the independent existence of mathematical objects and relations but also believes that the 'reality' of that world explains the universal nature of mathematical truth. However, Platonism, although popular among mathematicians and scientists, runs into serious problems when confronted with the applicability of mathematics. In this case, the basic problem is to answer how these Platonic entities, which do not have spatial or temporal characteristics, can ever get in touch with our physical world, which is defined by spatio-temporal extension. In other words, how do we as humans access these Platonic objects? And how do these objects link up with our real world?

Logicism: One dominant view of mathematics relates it intrinsically to logic. Logic elucidates the structure and validity of arguments. Reduction of mathematics to logic, in particular deductive logic, meant that the complete domain of mathematical activity was a logical one. Echoing this, the influential logician and philosopher Frege argued that 'mathematics was nothing but the systematic construction of complex deductive arguments', a view which has been dubbed the logicist view of mathematics. Russell attempted to show that all mathematical concepts could be redefined in terms of purely logical concepts. The reduction of mathematics to logic would then imply, for Russell, that all of mathematics, including its axioms and postulates, could be derived entirely from logical laws. However, as Dummett notes, there are various problems for this reduction of mathematics to logic that includes Zermelo's axiom of choice and the axiom of infinity. Moreover, there was a serious problem even

with a fundamental mathematical entity, the set. If logicism is right, then a set should be a logical concept. However, it was clear that a set was not a logical concept – one reason being that there are many incompatible axiomatisations of set theory.

Formalism: Another view of mathematics, influential in its own way, is called formalism. This school was largely associated with the German school of mathematics and most notably with the illustrious mathematician David Hilbert. The basic idea in the formalist view of mathematics is that mathematics is nothing but a set of rules and formal manipulations of mathematical symbols and terms according to these rules. For formalists there are no meanings attached to mathematical objects, equations or operations over and beyond these meaningless formal manipulations, whether in proof or applications. An analogy that has often been made is that mathematics is like a chess game, which has its objects such as pawns, queen, king and so on and rules of movement for each of these pieces. The formalist view of mathematics argues that there is no meaning to mathematics over and beyond the game which is played with these mathematical objects according to some given rules. Not only was Hilbert a strong proponent of this view but so was G. H. Hardy who believed that mathematics was just like chess. Moreover, Hardy describes even formal mathematical proof in terms of the structure of chess: 'The *axioms* correspond to the given position of the pieces; the *process of proof* to the rules for moving them; and the *demonstrable formulae* to all possible positions which can occur in the game.' The basic problem with formalism is that it seems difficult to accept mathematics as just a game; in particular its applicability to the sciences then seems totally arbitrary and forces us to ask, why is not chess applicable to the world like mathematics is? In fact, Frege believed that it is the applicability of mathematics alone that makes mathematics more than just a game. On the other hand, for Hardy, the very idea of applying mathematics was distasteful and he writes that mathematics which has practical uses is 'on the whole, rather dull' and has 'least aesthetic value'.

Intuitionism: In contrast to formalism is intuitionism. The father of intuitionism was Brouwer who drew upon the German philosopher Immanuel Kant's ideas of intuition and a priori truth of mathematics. For the intuitionists, mathematics is something to be created and not discovered, and the role of a creator is best exhibited when the mathematician has to exhibit proof for all existential mathematical assertions. Intuitionism has also been associated with claims that one can perceive mathematical entities. The intuitionists find the idea of infinity problematic and Brouwer argues that the formalists' approach to infinity and transfinite set theory is 'meaningless' since these are beyond the limits of mathematical intuitions.

Mathematics as language: Finally, let me consider briefly the view that mathematics is a product of human imagination, grounded in our experience with the world and functions like a language. First is the obvious fact that mathematics is a product of humans and is created through our interaction with the world. This implies that the world catalyses mathematical ideas, including the kinds of mathematical entities such as numbers, sets, functions and so on. For example, the mathematical principle of linearity illustrates the physical principle of superposition. If we think of mathematics as beginning with numbers and with some operations like addition we can find an immediate link between human experience (including the activity of counting and aggregating), the structure of the world around us and mathematics. While this does not mean that every mathematical entity or operation is somehow connected to our activity in this world it suggests that the distance between mathematics and our world is not that far removed in the first place. And this relation between the world, humans and mathematics can be analysed in different ways: mathematics as anthropocentric, as arising from our interaction with the world and influenced by a particular kind of pictorial cognition which influences the way its discourse is created. These views of mathematics offer a canonical answer to the puzzle of unreasonable effectiveness of mathematics. Part of the puzzle lies in the mysterious of the relation between two

different kinds of worlds – the physical and the mathematical. But if we question the proposition that these are different worlds and argue that mathematics actually 'arises' from the world then the unnatural connection is no longer there, thereby diluting the puzzle as far as this relation is concerned.

So we find that there is no simple answer to what mathematics really is. In the context of applicability this ambiguity about the scope and depth of mathematics gets transferred to the question of applicability. The mysteriousness that is enshrined in the phrase 'unreasonable effectiveness' of mathematics reflects as much a confusion about the mysteriousness of what mathematics is as much as its applicability. Moreover, there are many different types of applicability and different meanings to applicability. I will briefly discuss this issue in a later section.

Mathematisation in modern science: Lessons from the early days

How exactly did mathematisation of the sciences begin? Historians trace the origin of the modern sensibility of mathematisation from Galileo onwards although he was not the first person to use mathematics to describe the world. The Greek placed mathematics on the highest pedestal; as is well known, the golden section was one of the most privileged concepts in Greek art, architecture, ethics and science. Indian astronomy made extensive use of mathematics, as did Ptolemy. But what was special to Galileo was that he combined mathematics with experimentation, thereby justifying his being called the father of modern science – although in the next chapter we will see how such a singular title to Galileo is challenged by historians who argue that similar ideas came to Europe from various other cultures. In particular, the use of mathematics as well as the combination of theory and experiment as scientific method characterises the work of the famous Arabic scholar, Al-Hazen, much before Galileo.

Let me analyse one particular component of Galileo's method to illustrate why the method of mathematisation seems to work so effectively. Galileo's mathematics was not calculus but number

sequences. He discovered by his experiment on motion that distance of free fall of an object is proportional to the square of the interval of time. How does mathematics manifest itself in this case? Let us assume that we have the necessary apparatus to do this experiment. We drop a ball and find the distance it travels after one second, two seconds, three seconds and so on. Just by noting the distance travelled, we can see a pattern, which is that the distance fallen is in multiples of 4, 9 and so on. Without needing to know any physical laws or calculus we can conjecture that distance varies as the square of the distance.

The basic point is this: a pattern about free fall motion is discernible by a particular kind of observation that measures some parameter, in this case distance. Neither the act of measurement nor the use of numbers alone constitutes mathematisation of this problem. But what they do is to illustrate a pattern about motion which is not otherwise discernable. That the distance varies as time squared is of profound importance – this observation plays an important role in helping Newton postulate the gravitational force law as an inverse square law.

Suppose somebody claimed that we could as well have described the fall of the object in English instead of mathematics. So when asked to describe this free fall, this person could say that the object falls fast, faster and ... Note that in using English we do not have the capacity to specify the relation between fast and faster. Mathematics, as a language, has this capacity to tell us something about relations. It can tell us that the distance fallen after two seconds is not only greater than the distance fallen after one second but that the distance is four times more. So the use of numbers gives us more information about the distances as compared to the use of phrases such as 'greater than'.

But this still does not explain the mystery of mathematisation. Suppose we had numbers but did not have multiplication or the concept of proportion. Then we can conceivably give values for distance fallen but we will find no proportional relation between

them. Say an object falls 16 ft after the first second and 64 ft after the second second. Let us suppose (however improbable it may seem!) that our mathematics has no concept of multiplication and division but only addition. Then looking at these numbers we cannot find the law that distance varies as time squared. So just having numbers is not enough but we also need an appropriate set of operations. The question therefore is: if we discover new operations and new kinds of numbers would we be able to have a 'better' description of nature? But how do we know what operations are needed? Can nature tell us that? Or does mathematics first offer us this? Also, note that there are already prior physical concepts in use even in this simple problem. For example, the idea of distance. Even in a simple mathematical description there are many physical concepts which makes mathematisation possible. For example, before Newton's law can be written down in a mathematical form the physical ideas of force, mass and acceleration need to be present. Describing acceleration as a second-derivative comes after the physical intuition of acceleration as a 'property' of the moving object. Thus, the miracle is not in the use of second derivative as Wigner has it but in the discovery of acceleration as an essential physical concept. Even in the case of Newton's equations, Newton himself notes in his *Principia* that Galileo had known the first two laws of motion – this without the use of the second derivative!

Descartes, one of the most influential mathematician and philosopher of all time, believed that physics is a branch of mathematics as well exemplified by his statement that 'no other principles are required in physics than are used in Geometry or Abstract Mathematics, nor should any be desired, for all natural phenomena are explained by them.' However, his view on mass is an instructive example about the pitfalls of ignoring the differences in the ideas of the physical and the mathematical. Consider two ways of characterising mass: mass as extensional and as point-like. In one sense, mass as extensional reflects a brute facticity whereas mass as point-like seems to be counter-intuitive to the common sense.

Descartes, for all his belief that physics is a branch of mathematics, conceptualised mass as being extensional. Newton, on the other hand, believed that the essence of mass was to be point-like, a move which allowed him to formulate his physics. Although Descartes had formulated the principle of inertia which was 'formally equivalent' to that of Newton, he did not discover Newtonian physics partly because of his belief in the essence of matter as being extensional. Descartes' belief that physics was a branch of mathematics came in the way of his acknowledging the importance of experiments in physics. Although he had formulated his rule of inertial motion and set of rules of impact, they were incorrect because he did not consider the vector nature of momentum. Cohen notes that Descartes could have easily discovered his mistake by simple experiments.

As a final example, I will briefly consider a seminal contribution of Newton to the process of mathematisation. This particular method of mathematisation which he initiated continues to influence the way mathematics is used in modern science. Cohen isolates one aspect of Newton's use of mathematics, what he calls 'Newton style', as illustrated in Newton's derivation of Kepler's law. First, Newton considers a purely mathematical system, nothing to do with how the world is but dictated by the concerns of pure mathematics. Here a 'single mass-point moves about a centre of force'. Mathematically, if the centre of force is stationary and if the force is always directed towards the centre then Kepler's law of areas can be derived. This is a mathematical problem and treated as such. From this model he goes on to derive the other laws of Kepler, under appropriate conditions. After doing this, Newton compares this imaginary world with the real one. This immediately necessitates him to deal with two-particle motion since the centre of force is also a massive object. Then he develops the mathematics of this system. Next when he compares his model with the real world, he finds that he has to take into account a much more complex world which has more than two bodies in the solar system. This dynamic interplay between mathematical ideas and comparison with the physical world made Newton realise that

laws are absolutely correct only as mathematical laws but in physics they are only approximations (what he called 'hypotheses'). Today much of mathematisation is a continuation of this method (that is, the creation of ideal models) along with the concomitant realisation of the important role of the notion of approximation.

What exactly is being mathematised and applied?

Let us begin with a catalogue of the furniture of mathematics – there are objects such as numbers, sets, functions and matrices; operators such as the ones used in arithmetic and calculus; rules of operation which make possible calculation; the equality sign (and associated with it appropriate inequalities) and a host of concepts such as continuous, analytical, differentiable and so on. So the first point to note is that applying mathematics could mean applying any or all of the above elements that belong to mathematics.

What is mathematics being applied *to*? Even in the simple example of applying a number we notice an interesting facet of application. For example, let us say that we first start with a statement (in English): 'there are some apples on the table', then apply the concept of number to this and get, say, the statement 'there are ten apples on the table'. This is a proto application of mathematics. But what is getting applied to what? Here, the idea of a number is being 'applied' to a sentence in English. The concept of number is not being applied to the real apples in the world but to a particular description of the world which is first expressed in English with the help of the word 'some'. The lesson from this simple example is one that is central to the process of mathematisation: mathematics is first and foremost applied not to phenomena in themselves but to descriptions of phenomena. The two common modes of describing phenomena are through language and through idealised models (and it is arguable that models themselves are one kind of linguistic description). Here I would like to focus attention on language and in particular consider the possibility that the first defining characteristic of mathematical application is not the application of mathematics to the world as

such but to other language(s). One way of understanding this is as follows: models and languages mediate between mathematics and the physical world.

Consider the example given by Wigner. Wigner was surprised that a second-derivative, which stands for acceleration, was integral to the mathematical formulation yet had no common-sensical correlate. But did Newton really write his equation this way? It is well known that in *Principia* Newton states his law as follows: 'The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.' What exactly has been mathematised in this case? Where is the mathematics in Newton's law expressed in the modern form which says force is equal to mass times acceleration? In writing force as F, there has really been no mathematics done. In the usual form of the equation F = ma (which was not done by Newton but later on by Euler), we only have a *symbolic shorthand* for a longer sentence and this simple strategy is an important element of mathematisation. Moreover, force, mass and acceleration are *not* 'mathematical' concepts. They are physical ideas and the genius of Newton lay in formulating the *appropriate* physical concepts first. (For Galileo, appropriate for science implies that they can be measured.) The mystery for Wigner would lie in the fact that the physical idea of acceleration can actually be correctly described by a second derivative.

Mathematics is therefore applied not to the world but to language and this application can even be in the form of creating appropriate symbolisations. It may also be argued that mathematisation is actually an application of mathematics to (idealised) models. In the case of planetary motion, for example, one applies mathematics to idealised pictures and models of the planets. The use of mathematics in order to create new descriptions of pictures and models is also closely related to the mechanism of applying mathematics to language. In the next section I will discuss a little more about this particular process of application of mathematics.

Finally, the common belief that there is a miraculous correspondence between mathematical entities and physical concepts might suggest that recognition of this correspondence is instantaneous. But this is hardly the case. Physical concepts like mass or force get refined over centuries. During this process, they come to be associated with various physical and mathematical meanings till they settle down to some stable mode of description. The real mystery might occur when mathematics itself begins to supply physical concepts.

The problem is compounded when we consider the following: the space of mathematics is much larger than that which is applied or perhaps even applicable. There is a surplus of mathematics and only a part of it finds use in the sciences. And more problematically, the same mathematics can be used to model and describe worlds which are not only very different but also contradictory to our world. That is, as far as the truths of our world are concerned, mathematics is quite indifferent to them. And if we believe that science correctly describes our world then this indifference of mathematics to the 'truths' of our world is a potential embarrassment for science if we want to claim that mathematics is essential to it.

Explaining the obvious: the unreasonable effectiveness of language

Here is one possible way of analysing the usefulness of mathematics in the sciences. Firstly, mathematics constitutes a particular kind of description of the world. Description is an activity of language. Languages describe the world around us. Different languages offer descriptions that are unique to that language. The unique elements of a language include the kinds of concepts the language possesses, its grammatical structure and its larger vocabulary and meaning. A given phenomenon can in principle be described in different ways by using different languages.

The capacity of language to 'correctly' describe our world is already mysterious. The problem is simple. Assume that the world is given to us. The world, distinct from language, is nothing but a collection of objects and events. Language arises in learning to

talk about the objects and events of the world. Language not only seems to give us a 'proper' description of the world but also allows us to negotiate and intervene with the world in various ways. For simplicity, in what follows let me consider English as an example of a language. Describing the world with the help of English seems to capture some important facets of the world. Consider this simple example. Say we are seeing two objects in front of us and we describe our perception by saying 'one object is to the left of the other'. The capacity of English to create a word called 'left', which describes not an object in itself but a relation, is itself surprising but what is more amazing is that the linguistic statement 'one object is to the left of the other' seems to correctly match with our perception. But we somehow seem to take it for granted that there is no mysteriousness in the capacity of English to describe the world. We do not think that the use of English suggests an 'unreasonable effectiveness' just as the use of mathematics does. What could possibly be the reason for this lack of surprise at the role of language?

One possible reason is this: a natural language like English seems to largely arise out of our interaction with the world. The word 'tree' denotes an object tree – suggesting that we create a word in our language to say something about an object that we already have in front of us. We can name by pointing to things and children often learn the association of a word to a thing through the act of pointing. In this naïve sense, words in a language seem to be derivative to the real world around us and arise in response to the given world. Objects and events surround us and we use language to talk about them leading us to the commonly held view that the world comes first and language follows the dictates of the world. This in a way reduces the mysteriousness in the act of using language to talk about the world, because it is *expected* that a natural language like English, since it arises from the wellspring of the world, should well describe the world.

And this is exactly where mathematics is seen to differ from English. Mathematical objects are not seen as those that belong

to the natural world. Many mathematicians and scientists in fact believe quite the opposite – namely, mathematical entities belong to a Platonic world. However, mathematics functions in a way similar to natural language in the sense that the mathematical language is also a language, one which describes the mathematical world. For example, it gives names (such as 'sets') to mathematical objects (namely, sets), presumably existing in the world of mathematics. Therefore, the surprise is all the more exaggerated when it is found that mathematical objects, which presumably exist independently of our physical world, are very apt in describing our physical world. The surprise arises in finding that mathematics is doing a work which it supposedly need not be doing. And ironically, it seems to be doing it 'better' than natural language. In what sense is it doing a better job?

That mathematics does a better job than natural languages is perhaps most forcefully explained by the predictive success of the sciences based on mathematics. It is the predictive success of the sciences, based on mathematics, which gives the most important validation of mathematics. The mysteriousness of the effectiveness of mathematics is enhanced when a scientist stumbles upon a mathematical term which is then found to be the best fit to a particular physical description, like in the case of groups and symmetry or gauge theory and fibre bundles. Echoing this sentiment, Weinberg says that it is 'positively spooky how the physicist finds the mathematician has been there before him or her.' (However, we should also note that stumbling upon the right mathematical terms is quite similar to a musician stumbling upon the right notes or a poet stumbling upon the right word or phrase. What special value can be added to a 'right term' just because one stumbles upon it?)

However, both these descriptions of the character of English and mathematics are only partly right. English, although arising from a response to our natural world, also has the capacity to generate words which stand for physically non-existent objects. Abstract nouns, for example, refer to an abstract entity. Even the very act of having a word 'number', referring to a mathematical entity number, shows the

capacity of natural language to refer to things which are beyond our physical world. Moreover, English generates a large amount of words which have nothing to do with physical objects. And the flip side of this is also that mathematics is not to be understood as being totally concerned with a Platonic world. So both English and mathematics share some important, common features of languages, including the capacity to use both of them in different kinds of predictions. Mathematical description seems to be far more suited to certain types of description, typically quantitative, whereas a description in English may have superior qualitative expressions.

There are also some important differences between mathematics and English that we need to note. (I do not subscribe to the opinion that the degree of precision and non-ambiguity distinguishes natural language and mathematics. The association of precise meanings with mathematical terms and ambiguity with English words does not represent the true picture. One can see the presence of metaphorical imagination throughout the discourse of mathematics. The essential relation between mathematics and natural language, like English, makes this distinction between them more problematical.) In the context of applicability, I believe that the most important distinction which we need to focus upon is the observation that mathematics is not 'one' language like English. It is actually a collection of sub-languages each of which has some common links. Geometry, algebra, topology etc., are sub-languages of a larger entity called mathematics. These are sub-languages in the sense that they function like a separate language in terms of the concepts they possess, the methodologies they use, their aesthetics and so on, yet share a common world with each other. Each discipline of mathematics is actually like a sub-language and in talking about mathematics as a language, as something homogenous, we overlook this important diversity and difference of its many sub-languages.

This diverse character of mathematics is very important and actually offers an explanation of why mathematics is so unreasonably effective. The different sub-languages that constitute mathematics

make the descriptive enterprise of mathematics very interesting. Languages, when they are used to describe, explain, define, argue and so on, have specific narrative structures. Languages create narratives. A description is one kind of narration. The nature and the effectiveness of the description depend on the narrative structure of a language. In mathematics, the narrative structure is composed of the different elements of its different sub-languages, thereby expanding the scope of its narrative capability. Therefore, description in mathematics consists of much larger and more complex narratives than description restricted to only English. Let me give a simple illustration of how this is done.

Consider light reflecting from a mirror. How can we invoke mathematics here? What kinds of descriptions can we develop about this event with the use of mathematics? First, as is commonly done, we can give a pictorial representation of this process. The mirror is represented by a straight line and the incoming ray and the outgoing ray by two straight lines. Drawing the normal, we have the angle between the rays and the normal. This pictorial representation is very useful for science in that it allows us to do what we want with an idealised system. Mathematics comes into play on this idealised picture when we 'name' angles and use properties of terms such as momentum. So from a picture of the process we move into geometry (a sub-language of mathematics) of the system. This allows us to define and describe components of the momenta, forces and so on. At this stage we begin to do geometry – in the particular case of the reflection of light we do geometry on a plane. The results of these calculations will depend on some results that belong to the domain of this geometry and not the domain of the real phenomenon.

So typically this is what happens in the process of mathematisation. The event in the world is first represented pictorially, for example, which can then be expressed in another sub-language, say geometry, and then in algebra and so on. Each one of these steps takes the real world event into different narrative domains. For example, light bouncing off a mirror has no velocity component in the real world but

a mathematical description talks as if the components of momentum are real. So the shift into pictures and other sub-languages succeeds in adding new descriptions of the original event. It is important to note that these descriptions are unique to the different sub-languages. Description in the pictorial form is very different as compared to the ones derived from the geometrical narrative, which is itself very different from the one derived from using algebra. For example, once we enter the descriptive space of algebra we have a new vocabulary that is open to us to describe the process: continuity, rate of change, equations of motion and so on. This vocabulary, which was not present in the earlier sub-languages of pictorial representation or geometry, succeeds in expanding the narrative possibilities of this process. In the realm of algebra, the vocabulary allows us to talk of motion in higher dimensions, the possibility of transformations of co-ordinates, even the physically non-intuitive idea of transforming momenta into co-ordinates and so on. The important sub-language of calculus along with algebra allows us to develop extremely rich narratives about a simple process such as a ray of light bouncing off a mirror.

Thus, we see that the process of mathematisation using the many sub-languages of mathematics enlarges the possible descriptions one can have of a process. There are literally no conceivable limits to what sub-languages we can use for this description. If, for example, someone finds the vocabulary and grammar of topology useful in the description of a bouncing ball then it becomes part of the larger mathematical description of this process.

So, first and foremost, using mathematics to describe the physical world is a means of finding ways to create multiple descriptions of a physical object or event. We can see that a language like English will only create limited narratives about a phenomenon because it doesn't have the rich sub-languages that mathematics has. When we use mathematics as a language to describe a process we first of all create a rich storehouse of possible narratives. What among them will fit the world is an issue that mathematics is unconcerned about. The job of mathematics in sciences is essentially to proliferate narratives and the more number of narrative descriptions are possible the better *probability* that there will be a fit somewhere, sometime.

The above discussion indicates the complexity involved in the process of mathematisation of the world. The great challenge to science will lie not only in the creation of new mathematics but also in the possibility of creating new modes of expressions and new languages in the unending scientific search for mapping the universe.

Sociology of Truth and Knowledge

There is much of the language of the psychological (such as using words like I, phrases like 'my belief', words that connote emotions and so on) that is kept hidden in the expressions of scientific knowledge. Hiding the psychological is a rhetorical strategy which is put to good use in science. In the case of science, the psychological is not explicitly considered or mentioned.

Over the last few decades, there has been sustained work which critically analyses the nature of knowledge and the ways in which it is produced. Knowledge is a social commodity and it is intrinsically linked with the discourse of power. Knowledge is produced by a community of individuals as part of well established institutional structures. Knowledge is also culturally mediated, suggesting thereby that what constitutes knowledge for one culture may not be the same for another culture. A good example of this is the local medical systems of various cultures. They can all be seen as knowledge systems related to health and the body but they may significantly differ in the concepts and theories that are used in these practices. For example, Āyurveda is a medical knowledge system which is based on a particular theory of the body and health, and allopathy is another medical knowledge system which is based on a different theory of the body and health. Thus, in principle, different cultures produce different kinds of knowledge and what gets accepted as such is part of a process which is 'political' in nature. Such views have also led to claims of feminist epistemology, which would suggest that 'women'

see and construct knowledge differently along with the assertion that dominant knowledge like scientific knowledge is 'masculine' in character. Similar arguments arise in the case of ethnic or local knowledge.

Obviously, science resists such claims about the political and cultural aspects of knowledge. It also strongly resists any claims of feminist epistemology; a standard response to such claims is to ask whether the laws of science would have been different if women had created science. Or would mathematical propositions be different if mathematics was essentially created by women?

One of the ways by which we can make sense of these claims of different knowledge systems is by focussing on the idea of facts. Science is a discourse of facts and it is believed that facts are present in nature and discovered by scientists. The sociological theorists of knowledge would even dispute this claim for it is not obvious whether facts are created or discovered; are they co-constituted or merely given? Is it a fact that the solar system has nine planets? Is it an eternal fact? Can it depend on human categories? Can it ever change?

If we look at the issue of facts closely, we do find that they are not as unambiguous as science claims them to be. Facts do change. For example, an accepted fact until recently was that there were nine planets in the solar system. Now scientists tell us that there are only eight planets. It is not that Pluto has fallen off the solar system but that the scientists have decided that Pluto is not a planet after all! In other words, there is really no fact of the matter that made Pluto a planet. It was a category which we created and into which we initially put Pluto into but later on decided on its removal from that category. So what really is the fact about the number of planets in the solar system? The only fact that is available is the fact related to concepts called planets and solar system. Once scientists create a category called solar system and a concept called planets (the real problem here is in defining what a planet is – a planet is not just something that goes around the sun since moons and asteroids, for

example, also go around the sun), they find a relation between these ideas. Facts capture a particular ordering of the world given our basic human concepts. Many of these concepts are dependent on culture and human interests. For example, for a culture that does not believe that there is a solar system and that the sun is actually part of a more complex structure then there is no fact either of the solar system or the number of planets in it. If a culture has a wider definition of planet which includes moons then in this culture the fact of the number of planets in the solar system will differ significantly.

All that this suggests is that if humans create a concept then they can find some factual characteristics of it. So if we create a concept called charge we will find a fact of the charge of an electron as being equal to a particular value. If we had not 'discovered' this concept then there is really no fact associated with a charge. This view has two consequences: one is that facts of the world are not mere 'truths' of the world but are in a complex relationship with the way humans see the world. Secondly, this also implies that there are many more 'facts' in the world which we have not discovered not because we don't have the instrumental capacity to do so but because we have not yet imagined the concepts related to these facts.

A supporter of the view of the scientific view of facts might respond by saying that concepts are also discovered in the world and that in fact concepts themselves are there in the world like objects. There are influential theories in Western philosophy which holds this view that concepts are 'real' and out there in the world. In this view, a scientist is as much discovering a concept as she does a fact. The only difference is that if concepts are real they have to be a different kind of entity, perhaps an abstract entity. (As we saw in the earlier chapter on science and reality, reality has nothing to do with something being abstract or not. Abstract entities can be as 'real' as concrete entities.)

So the question of whether women could have created a feminist science, whether 2+2 is always 4, whether there really are quarks and genes, whether Indians do science differently are all complex questions that cannot be answered by science alone. Science, as

practiced today, does indeed project a male-centric, modern Western worldview based on a specific view of reason and of nature. This means that the concepts, ideas and language which create new science are influenced by this particular sociological aspect of science. Now that science is practiced across the world and scientists come from many diverse groups, one might argue that these characteristics can no longer be part of contemporary science. But there are no easy responses to these claims and counter-claims. All that one can say at this point is that science's views of truth and knowledge are indeed very restricted to particular ways of looking at the world, particular cultural values and particular methodologies. One must keep this in mind when we try to universalize the scientific method, approach, worldview and assumptions to other aspects of human endeavour.

References and Further Reading

The following books can be used as background material on epistemology:

Athearn, Daniel. 1950. *Scientific Nihilism: On the Loss and Recovery of Physical Explanation.* New York: Simon and Schuster.

Audi. R. 1998. *Epistemology.* London and New York: Routledge.

Landesman, C. 1997. *An Introduction to Epistemology.* Oxford: Blackwell.

Lipton, Peter. 1991. *Inference to the Best Explanation.* London: Routledge.

Oldroyd, D. 1986. *The Arch of Knowledge.* New York: Methuen.

Sosa, Ernest. 1991. *Knowledge in Perspective.* Cambridge: Cambridge University Press.

For some interesting readings which show that science is a social enterprise, see:

Collins, H., T. Pinch. 1998. *The Golem at Large: What You Should Know About Technology.* Cambridge.

Collins, H., T. Pinch. 1998. *The Golem: What You Should Know About Science.* Cambridge.

Collins, H., T. Pinch. 2005. *Dr Golem: How to Think About Medicine.* University of Chicago Press.

Harding S. 1986. *The Science Question in Feminism.* Ithaca: Cornell University Press.

Harding S. 1998. *Is Science Multicultural? Postcolonialisms, Feminisms, and Epistemologies.* Bloomington, IA: Indiana University Press.

Knorr-Cetina, K. D., and M. Mulkay., eds. 1983. *Science Observed: Perspectives on the Social Study of Science.* Beverly Hills: Sage.

Latour B. 1987. *Science in Action: How to Follow Scientists and Engineers through Society.* Cambridge: Harvard University Press.

Sarukkai, Sundar. 1999. "Science, Knowledge and Society". *Economic and Political Weekly,* Vol. XXXIV.

A classic essay on the effectiveness of mathematics in science, referred to in the chapter:

Wigner, Eugene P. 1960. "The Unreasonable Effectiveness of Mathematics in the Natural Sciences." *Communication of Pure and Applied Mathematics.* 13.

Sarukkai, Sundar. 2002. *Translating the World: Science and Language.* Lanham: University Press of America.

Sarukkai, Sundar. 2005. "Revisiting the 'Unreasonable Effectiveness' of Mathematics." *Current Science* 88.

About the nature of mathematics:

Rotman, Brian.1993. *Ad Infinitum: The Ghost in Turing's Machine.* Stanford: Stanford University Press.

Field, Hartry. 1989. *Realism, Mathematics & Modality.* Oxford: Basil Blackwell.

Jacquette, D. Ed. 2002. *Philosophy of Mathematics: An Anthology.* Oxford: Blackwell.

Kline, Morris. 1985. *Mathematics and the Search for Knowledge.* New York: Oxford University Press.

For more on scientific method:

Gower, Barry. 1997. *Scientific Method: An Historical and Philosophical Introduction.* London: Routledge.

Glymour, C. 1980. *Theory and Evidence.* Princeton: Princeton University Press.

Salmon, W. 1998. *Causality and Explanation.* Oxford: Oxford University Press.

For a succint account of the scientific revolution in Europe, see:

Henry, John. 1997. *The Scientific Revolution and the Origins of Modern Science.* London: Macmillan Press Ltd.

A classic introduction to the sociology of science is:

Merton, Robert K. 1973. *The Sociology of Science: Theoretical and Empirical Investigations.* The University of Chicago Press.

For a more recent introduction, see:

Bucchi, Massimiano. 2004. *Science in Society: An Introduction to Social Studies of Science*. London: Routledge.

For a classical work on Indian theories of knowledge:
Matilal, Bimal K. 1986. *Perception: An Essay on Classical Indian Theories of Knowledge*. Oxford: Clarendon Press.

VI

Science and the Human Subject

Science has successfully created an image of universality. This is possible only because science is seen as (or reduced to) a collection of truths about the universe and these truths, following a particular Greek tradition, are presumed to be universal, eternal and unchanging. So, if science is only a collection of truths about the universe, then it makes sense to say that science itself is universal and unchanging across time and cultures. When we use the word 'science' in this context, it means science as a body of knowledge. The proponents of the universality of science might agree that when seen as an activity science might embody certain non-universal traits.

As we saw in the last chapter, truths in science are characterised by fallibility – they are often rejected or undergo modification. They are also dependent on various pragmatic concerns and thus directly related to human aims and objectives. There is really very little in scientific truths that can really live up to the standards of mathematical and logical truths. The latter are characterised by strict necessity (it has to be so) whereas scientific truths are contingent (it happens to be so).

What is the role of the human subject in the formation of these truths? That is, how much does an individual scientist's personal history, culture, proclivities and bias influence the scientific truths she 'discovers'? While sociology of knowledge has allowed us to understand the nature of scientific knowledge and truth in a non-universal context there is nevertheless strong resistance from scientists

and others who prefer a more traditional understanding of science in which the universality of science plays an important part.

What really is at stake in this claim of universality? Science has been influenced by, and in turn has influenced, the European Enlightenment. In particular, it is indebted to the Enlightenment credo of giving an individual the full autonomy to reason for herself. Kant's famous call to dare to reason is an illustration of this responsibility and autonomy which each one of us possesses. Our reasoning does not have to be validated by religion or by the State. Each one of us has the right to reason. This view allows the creation of the idea of an autonomous individual and very strongly influences the development of the modern Western civilization. One of the essential elements of this idea of reason is its impersonality. Reason is characterised by universality and this means that the products of reason also have universal value. So, although it may be an individual scientist who discovers a truth of nature the truth is itself universal because the discovery is through the process of reason which is universal.

It is in this sense that the notion of the subject is so problematical not only for science but for accounts of truth and knowledge. A scientific truth cannot be legitimized by the claims of an individual however 'great' that person may be. The individual may discover a truth but it needs the collective to accept it as such. What this means is that the individual, the 'I', has to be erased and removed from scientific expressions. Science as a practice follows this dictum well. An unwritten but effective rule in scientific writing is the absence of any reference to the self such as using 'I'. Scientific papers properly report and scientists are only reporters doing an impersonal job of reporting the status of the world. So any mention of I is anathema in a scientific paper for it draws attention to the scientist as an author. Scientists are not authors – they can be, at the most, only translators of the book of nature or as I have elsewhere suggested, they are only pseudotranslators (Sarukkai 2002).

There is a rhetorical strategy in the writing of science that clearly

illustrates this attempt to remove the individual from scientific claims. All expressions of science replace human beliefs by facts – so instead of saying that Einstein believed that $E = mc^2$, we say that $E = mc^2$. One way by which this personal opinion becomes a fact of the world is through support from the collective. That is, a belief of the individual becomes a scientific fact when it becomes a 'belief' of a collective, when the 'I' is replaced by the 'we'.

By removing the I from scientific truth and knowledge, science is able to accomplish a lot in one stroke. Since the individual subject is the locus of history and culture, this erasure of the individual means the removal of the historical and the cultural from the claims of science. For the practice of science, the only category that is relevant is that of 'scientists'; categories like Indian or Chinese, men or women, cannot matter for science. So we cannot, in principle, have a science that is uniquely reflective of culture such as Indian or Chinese science, or masculine or feminine science. In other words, to be a scientist, to function like an ideal scientist, is to transcend the locality of the human subject, to transcend the historical and cultural grounding of the subject.

Science goes to great lengths to maintain this ahistorical and acultural aspects of its descriptions of nature in terms of its practice, its rhetoric and its self-image. Students are taught right from the beginning that scientific truths are completely independent of human interests. But ironically, claims that women cannot do science (a surprising claim voiced and believed by many scientists, most notably Einstein among many others), end up privileging a particular class of people who have the capacity to do science. The history of science clearly illustrates the strongly entrenched belief that people of different classes and cultures did not have the inherent capability to do science – whether it was women or Asians or Blacks. Infamously, German science and mathematics in the Nazi era rejected all science that was seen to be product of the Jewish mind and referred to such products as Jewish science and Jewish mathematics. But ironically, in all these acts, the scientists are essentially claiming that who the

individual is does indeed matter in the practice and product of science.

An important reason for this conundrum lies in the fact that science does not know where to place the human in its scheme of things. Biology illustrates this conundrum well. When we describe nature, are we describing ourselves as part of nature or are we outside nature? If we are a part of nature how is it possible for us to describe the whole of which we are a part? If we are 'outside' nature, in what sense are we outside since nature as a category is as much applicable to the humans also.

The inherent tension in categorizing humans as either belonging to or not belonging to nature is also reflected in the ambiguity in understanding the place of the human subject in the process of creating scientific truths. At one level, scientists recognize that scientific truths are a product of the human mind and imagination, which may be influenced by training, culture and other factors. But, at another level, scientific truths have to be independent of human interests and prejudices. This by itself is not a serious problem if we look at the analogy of a discoverer who goes around trying to discover new things in the world. How each explorer plans his or her expedition might depend on various socio-political and cultural factors but once something is discovered, say a new species of plants, then that discovery is independent of the human factors that catalysed the discovery.

The only problem in this analogy is that scientific discovery is often a discovery not of materially objective facts of the world – like a new plant or an animal – but more likely a 'discovery' of new concepts and properties which are not objectively accessible to all of us. (Even in the discovery of new objects like fundamental particles, there is no common understanding of the nature of these objects.) It needs very special perceptual powers (such as instrumental perception discussed earlier) to be able to see the fruits of discovery. Given this character of scientific truth, the analogy with an explorer's discovery becomes weak.

So, as some philosophers have claimed, scientific truths are not really objective truths but are truths that are accepted as such in a spirit of solidarity among the community of scientists. In so doing, the primacy of the human subject within the discourse and image of science is reinstated.

In the remaining part of this chapter, I will explore some aspects related to the role of the subject in the creation of scientific knowledge. I will begin with a summary of science in ancient India. I will then look at how modern science developed in Europe by drawing upon the scientific 'discoveries' of other cultures.

Science in Ancient India

Science, technology and mathematics flourished in ancient India. Sometimes such a statement evokes scepticism. While it may not be disputed that mathematics was highly developed in ancient India, and by now there is very good evidence that the Indian civilization made important technological contributions, there is still some scepticism about describing them as 'science'. Did the society of those times really practice what we refer to as science?

The problem is in naming something as science (see Chapter I). Since science in the modern era had a value attached to it, many activities try to present themselves either as belonging to science or least being scientific in some sense. But how do we evaluate whether something is scientific?

This question is important because in the larger project of colonialism and Orientalism, non-western societies were constructed in a specific way, one which did not grant them the capacity to be rational and scientific. Somehow being scientific was seen as a capacity available only to the modern Western mind. So when the first examples of Indian technology came to the attention of some Western scholars the responses ranged from absolute dismissal to attempts to make sense of them without giving the original inventors the power of reason and science. Thus, we have the British colonial discourse on Indian technology which tried to dismiss

the technological expertise of Indian society as mere artisanship or craftsmanship. In so doing, they were denying any method to those who created these complex technological products such as steel, zinc, alloys, dyes and so on.

There is no doubt that the ancient and medieval Indian society exhibited great advances in technology. The high quality steel which was produced in India was exported and used in the manufacture of the famous Damascus swords as well as Roman cutlery. The manufacture of zinc, which is a really difficult metallurgical process, was first discovered in India. The knowledge of the processes of manufacturing steel and zinc were taken by the British just as they appropriated knowledge in a variety of fields ranging from metallurgy to chemistry.

Do these examples of technological development point to the presence of 'science' in ancient and medieval India? An answer to this hinges on the meaning of science. As discussed in the first chapter, science is often used as a title which is bestowed upon others by a particular group. And for a variety of reasons, which includes simple motives like wanting to restrict access to public resources, many different types of systematic knowledge systems are not given this title of science. Instead of arguing that many of these forms of knowing, including the knowledge produced in mathematics, science and technology by non-European cultures, should be seen as science, let me offer another argument, one which points to how modern science is itself a product of knowledge taken from other cultures. Hence any attempt to keep these cultures out of the ambit of science is itself irrational.

The Multicultural Origins of Modern Science

Very often, when questions about the origin or priority of ideas are raised a standard response is often one of suspicion. Why should anybody be interested whether science or at least the idea of it was available to ancient civilizations? And when somebody raises these questions, what are they after? Do they want an acknowledgement

that different civilizations had the intellectual capacity for science and in this way claim a kinship with the intellectual tradition of Europe which has come to define the standards for the rest of the world? Or worse, do they want to appropriate a value essentially associated with Europe to other cultures such as the Arabic, Chinese and Indian?

The reason why anybody should be interested in these issues has as much to do with the nature of knowledge as it has to do with the way societies are shaped in contemporary times. Under the influence of the dominant paradigms of the Western Enlightenment, generations of students in Asia, Africa and the Middle-East are taught that the most important marker of intellectual thought – that of modern science – was a special creation of the European imagination. Alongside this claim, there is another more contentious claim: that other cultures not only did not create modern science but for various reasons they did not have the capacity to do so. If one thinks that these observations are exaggerations, all they have to do is to look at the content of textbooks and the sedimentation of the belief that the Western civilization is fundamentally superior to other civilizations when it comes to modern science, which stands as the exemplar of reason and rationality in today's world. The impact of such indoctrination on the self-confidence of non-West cultures cannot be underestimated.

Given this situation it is not a surprise that there have been knee jerk reactions to these claims of West's special relationship with science. One trend is to attack the project of science itself and point to some disastrous consequences of modern science. Another trend is to show how other civilizations 'had' science (and technology) to varying degrees. In the case of technology, the examples of Indian and Chinese technological innovations have been well analysed in the literature. In face of evidence of mathematics, astronomy and technological innovations in these civilizations, many now qualifiedly agree that 'other' cultures 'had' science but they did not have modern science. Once people were forced to acknowledge that other cultures possessed a sophisticated theoretical and experimental science then

the uniqueness associated with the Europe was sought to be captured through a different question: why did only Europe develop modern science while the other civilizations (although they might have had 'pre-modern' science) did not? This is the famous question posed by Needham as to why modern science developed in Europe and not elsewhere. This question is concomitant with the recognition that other cultures such as the Chinese and the Indian perhaps had prerequisites needed for modern science yet the transition did not historically materialize.

There have been many different types of responses to this question. In this section, let me analyse the arguments for a multicultural origin of science. There have been some claims on behalf of multiculturalism and I draw upon Bala (2006) who offers a sustained defence of this position. He begins by unpacking the assumptions inherent in questions such as Needham's. He first suggests that this question itself indicates an assumption about the universality of modern science since other 'local' traditions of knowledge are not considered as science. Second, there is an assumption that Greek 'science' is organically linked to modern science hence a similar question about the origins of modern science is not posed to the Greeks as it to the Chinese or Indians. Three, this question is predicated on a belief that other non-Greek cultures had no contribution to the creation of modern science. So in the dominant narrative of modern science, not only is an artificial link to the Greek tradition discovered but there is, at the same time, an erasure of the links to the Arabic, Chinese and Indian contributions in this creation of modern science.

Influential books dealing with Chinese or world knowledge systems continue to reinforce these beliefs even though some of them are sensitive to the complexity of knowledge generation and transmission. Very often an attempt to answer Needham's question leads to a set of reasons – positive reasons for the origin of modern science in Europe and negative reasons to explain why it did not originate in the Arab world, China or India. As Bala points out,

even in texts that understand the contribution of other cultures to science and technology, there is still a tendency to a Eurocentric view of science, a view that is characterised by two components – the belief that the Greeks contributed to modern science and other cultures do not for various reasons. Moreover, Greek 'science' is seen as autonomous and independent of other influences, particularly the Egyptian and the Babylonian, although all facts are to the contrary.

Multicultural histories of science naturally arise if the date of the origin of modern science is shifted backwards as Duhem indeed did. Duhem's argument that the origins of modern science should be traced back to the 14th century allows Bala to make an explicit connection between the influence of Arabic and Chinese cultures on Europe which was quite prominent in the medieval ages.

Most influential writers, even if they had been aware of the contributions of other cultures to science, mathematics, astronomy, technology and so on, resist accepting the influence of these cultures on modern science. The real challenge to the multicultural history of science rests on 'evidence' for the transmission of ideas from other cultures into Europe at the time when modern science began. Bala carefully considers grounds that warrants claiming which ideas from other cultures influenced ideas in Europe by isolating the notion of thematic influence. Drawing from Holton's notion of 'ideational themes' who pointed to the thematic influence in science, Bala suggests that we can make better sense of the question of transmission by looking at thematic influences and which leads him to propose a transmission criterion:

> 'If, shortly after a new corridor of communication opens between a culture A and a culture B, and great interest shown by A to understand B, a theme becomes dominant in A similar to a dominant theme in B, then we can presume that the development of the theme in A was due to the influence of B, even if the new theme had existed as a recessive theme in A prior to contact between the cultures'.

Bala notes that this criterion is a sufficient case for accepting transmission. He is also aware that European histories do not make explicit acknowledgement of such transmissions but that again is not evidence that such transmissions did happen since 'historical genealogies were constructed to interpret them as autonomous developments.'. The historical writing of Europe is a rewriting which consciously 'ignored the multicultural influences on Europe' as well as the dialogical process with other cultures. The dialogical argument, built around thematic influence, accepts that the development of modern science is a unique European achievement but alongside we need to accept the multicultural influences that made this happen – that is, 'modern science emerged in Europe through its dialogue with ideas found in other cultures.'

There are countless examples to support a multiculturalist position. Much of it has to do with examples of the influence of conceptual ideas from Arabic, Chinese and Indian cultures on Europe. Let me list only a few seminal influences.

Firstly, the Renaissance in Europe is often seen as a rebirth of Greek thought without acknowledging the influence of other cultures. Bala points out the seminal influence of both Arabic and Chinese cultures leading up to the Renaissance, an influence best exemplified by da Vinci. The curricula of University of Padua adopted that followed by Arabic institutions; the fact that this university was to become the alma mater of Copernicus, Galileo and Harvey points to the indirect influence of Arabic thought on these influential figures. Numerous Arabic works in medicine, astronomy and optics were translated from the tenth century onwards thus becoming available to European thinkers. The European response towards these translated works was conditioned by their attempt to link themselves to Greek thought. Thus they interpreted Arabic culture 'as a mere carrier of ancient European thought' thereby negating any ethical pressure to acknowledge them as originators of ideas that influenced not only modern science but the European Renaissance in general. Contrast this with the Arabic scholars who meticulously described their debt

to India and China. Bala argues that the Europeans 'invented the doctrine of a dark age that intervened between New Europe (the West) and Old Europe (the Hellenistic world) to facilitate the assimilation of Arabic scholarship into medieval Europe.'

Consider the Copernican revolution, which in standard accounts of science stands as a, if not the, prime event in the beginning of modern science. First of all, heliocentric theories were already available to the Greeks as well as to the Indians. Moreover, Copernicus' rejection of Ptolemy involved new uses of trigonometry as well as the rejection of the equant. Copernicus inherited his methods in trigonometry from the Indians and the rejection of the equant from Arabic astronomers. The Indian place-value number system along with zero made possible the computations by Copernicus. Indian mathematicians profoundly influenced Arabic scholars and they had already developed proto-theories of calculus, solving quadratic equations and so on. Vasco da Gama's arrival in Kerala (where these early theories of calculus were taught) in 1498 opened a corridor of communication to Europe. Following the criterion of thematic transmission mentioned above, we can explain the sudden emergence of these Indian ideas in Europe by the simple fact that these ideas significantly influenced European thought in these fields. For example, a book for students called *Yuktibhasa* on the work of the Kerala astronomy school which had various themes associated with calculus and one not written in classical Sanskrit, was available to European missionaries. The fact that it predates by nearly half a century the emergence of similar ideas in Europe is cause for some introspection on possible transmission of ideas. In other words, circumstantial evidence points to transmission of ideas so clearly that it would hold in any court of law today!

Similarly, there was a long tradition in Arabic astronomy which developed a critique of the use of equant in Ptolemy. It was also discovered that the 'solar, lunar, and planetary models of al-Shatir are mathematically identical to those proposed by Copernicus some 150 years later.' Given the similarities with the earlier Arabic Maragha

School, this has led to the observation that 'Copernicus can be looked upon ... as the most noted follower of the Maragha School.'

Bala's argument in this context, along with his observations about the development in optics catalysed by Arabic scholarship, allows us to seriously question the claim that Greek science was anticipatory of modern science and was quite close to it. The optical revolution which played a major part in the development of modern science was actually significantly influenced by al-Haytham's (Alhazen) work on optics. It influenced Grosseteste, Roger Bacon, Galileo and Kepler. As much as the scientific merit of Alhazen's work, there were also other impact of his theory of vision on Europe. Bala identifies two important consequences: firstly, a shift towards mathematical realism which was instrumental in influencing the way in which mathematics gets to be 'applied' and secondly, a 'profound shift in the perceptual sensibilities of Europeans.'

Yet another theoretical aspect has to do with the theory of atomism which again had an important role in the beginnings of modern science. Here again Bala convincingly argues about various traditions in atomism in other cultures and the influence they had on other categories, particularly that of necessary relations. In this context, it is worth remembering that Hume's critique of causality parallels that of al-Ghazali and even some examples used by Hume are the same!

So the first step in the argument for multicultural origin of science is to question the claim that modern science was somehow 'organically' related to Greek science as well as to the Renaissance. Following this one can look at how other cultures contributed to the development of modern science. The Arabic tradition built upon, synthesized and developed Indian, Chinese and Greek scientific and philosophical traditions. In the narrative of the origin of modern science, all these influences (except the Greek) are discarded. Needham suggests that the reason why Indian and Chinese contributions were ignored was the selective choice by European translators who ignored the Arabic texts dealing with India or China.

Bala then goes on to argue that the 'fusion of the concept of a universal mathematical law with the notion of a mechanical law is the outcome of the meeting in Europe of Arabic philosophy and science with Chinese mechanical discoveries.' And one of the great influences of this mechanical philosophy was in Harvey's theory of the circulation of blood and the model of heart as a pump. Given that the Chinese had a well established theory of the circulation of blood and heart as a pump, and that the European engagement with the Chinese was already a century old, could it have been possible that Harvey's 'discovery' was actually influenced by literature transmitted from China? While this does not negate original European contributions about the mechanical picture of the world developed in modern science it is nevertheless the case that this picture itself was influenced by Chinese theories (as well as medical literature of the Arabs).

Similarly, many other fundamental concepts which influenced Brahe, Kepler and Newton, among others, were based on ideas derived from non-Western sources. In this sense, the real revolution in the creation of modern science is this bringing together of diverse ideas from different cultural sources. As Bala reiterates, this is not to deny the uniqueness of the scientific revolution in Europe. He only wants to argue for a dialogical, multicultural basis for science while accepting that modern science is indeed a special accomplishment of the Europeans.

Such a multicultural perspective of the origin of modern science also helps in explaining why modern science began only in Europe. If the possibility of modern science lies in the confluence of ideas from Arabic, Chinese, Indian and Egyptian cultures along with the Greek, then it is only in Europe that such a confluence would have been possible. This geographic explanation of the origin of modern science should be contrasted with other attempts which draw upon stereotypes about people in other cultures who do not have the ability to reason or the role of religion in these cultures which inhibited the development of modern science. Many of these arguments are really

not sustainable and given the inherent weaknesses in such arguments, this geographical explanation seems far more reasonable.

So what exactly is the significance of the argument of multicultural origins of science? Are matters of priority really important? Definitely so, at least in modern science. The history of modern science is filled with claims and counter claims to priority. The institutionalisation of science valorises priority and rewards the first discoverer and inventor. Scientific publication is very much about being the first to publish a result. The intensely strong reaction against plagiarism is related to this obsession with priority. It is ironical then that given such meticulous attention to priority in modern science the first ideas that gave rise to modern science are not properly acknowledged!

Finally, we should remember that it is not a matter of priority alone but also of recognizing that in choosing one dominant paradigm (that of the West), a majority of the world's population is losing access to very different views about the world, the cosmos and our own place within it. And it is highly possible that it is within these differing traditions and worldviews that the future of humanity is to be secured.

Science and Religion

In earlier times, science validated itself by using the language of religion: Galileo was careful of what he said and how he said it; Descartes accepted a vague formulation of motion that would satisfy the Church's belief that earth was not moving; Newton called space the sensorium of godhead, re-emphasising the association of god with space and time which were based on the beliefs that infinite space was a manifestation of god's omnipresence whereas infinite time manifested god's eternality. Since geometry was associated with space and time with arithmetic (as manifested through the action of numbered instants of time and the process of counting following from it), god was thus essentially 'embodied' in science. Moreover, when Newton argued for the existence of absolute space he was arguing indirectly for the existence of god. In fact it is even said that

he held the view that the success of his theory was seen as a proof for the existence of god.

It is not surprising therefore to note that Newton's theory was hailed by the leaders of the Church as having scientifically proved the existence of god. The times then were such that it was felt by some that the 'new' science of that time questioned some fundamental tenets of religion. So when the greatest scientist of the times argued for the validity of his theory by relating it to religion, he was doing what religious communities are doing now.

In a world dominated by the hegemony of religion, early science accepted religion in various ways, thereby not entering into a direct conflict with the power of religion. In the Indian context, there is a similar story, although it predates modern science by centuries. This had to do with the acceptance of the Nyāya school. In the early days before this tradition gets established, there was a strong reaction against logic, which was associated with Nyāya, because it was believed that the followers of this tradition were atheists and against the Vedas. In order to gain legitimacy, the Nyāya school argued that logic was important because it could be used to demonstrate the existence of god.

Similarly, to validate the growing claims of modern science, scientists used not only categories of religion but also, where needed, explicitly accepted religious tenets. Even in mathematics the spectre of religion was not far off. In fact, it is in mathematical thought that there is a stronger possibility of discovering pseudo-theological doctrines. A good example is Cantor, the inventor of the 'paradise' of transfinite (infinite) numbers. Cantor was not only deeply religious but his inquiry into the nature of the infinite was influenced by his religious leanings.

The wheel has turned a full circle. What Newton did then, religion is doing now. The dominant intellectual culture of the modern world is scientific in spirit. Much religion has flowed beneath the bridge of modern science. The establishment of modern science in effect displaced religion as a dominant paradigm of understanding

the world so much so that there is a crisis of religiosity in the modern Western world.

Given that religion found itself on the wrong foot, especially in many Western societies which self-consciously described themselves as scientific, it is not surprising that they chose to respond to science in the way science responded to religion in the early days of modern science – that is, attempt to appropriate it. Religious institutions, across the world, now have a conscious agenda of engaging with science, of appropriating scientific terms and enlisting the support of scientists. The competition between science and religion is less about ideas of faith or even about the nature of the divine as it is about the social power they each have in modern societies. They see themselves as competing power structures in the social and political domains.

Today there is much that has changed in comparison to a few decades ago. Scientists are coming out of the closet. They are openly exhibiting and vocalising their religious preferences. In scientific institutions religion is no longer a taboo as it had been a few decades earlier. In the US, an increasing percentage of scientists are becoming vocal about their religious beliefs. In India, where scientists always lived with a vibrant living presence of religion more than their Western counterparts, it was anathema to exhibit any connection to the religious. To be scientific was commonly equated to being atheistic. This was especially so in premier research institutes in the country. Today, a visible shift is seen where scientists, many of them very competent ones, do not find a need to hide their religious faith.

Another illustration of this subtle but sure shift of the public legitimacy of religion among scientists is the creation of many programmes on science and religion today, which is sometimes presented as the science and spirituality dialogue. The game plan for the agents of religion is quite simple. To respond to science, first co-opt scientists. So most approaches to science and religion or science and spirituality talks about the role of faith in science or about how science is quite limited in what it can survey. The other dominant trend has been the training in the subjects of science to those in religious orders and institutions. (We should remember that this has always been an essential part of the Jesuit movement so much so that many leading scientists of their time were Jesuits.) Thirdly, there is an increasing trend by these outwardly religious institutions to fund scientists in order to catalyze work in the border of science and religion, or to generate scientific interpretation of religious doctrines and at the same time religious interpretation of modern science.

This is possible because of support from science itself. On the one hand, science is looking to expand its domain. There are increasing numbers of scientists around the world who think that studying problems such as consciousness is a legitimate scientific activity. On the other hand, the entry of scientific vocabulary into these soft areas opens up the opportunities for religious revivalism. Religious institutions have tacitly appropriated scientific terms in order to place themselves as partners with science in the larger human quest for understanding. While some part of it is genuine and deserves a deeper analysis, the political nature of this activity leads to not only mediocre scholarship but also vacuous claims of the relation between science and religion.

Moreover, there is another reason for this trend and this again is catalysed by science. The trend of shifting towards religion in societies that are dominantly scientific and technological in character is illustrative of a deepening sense of unease among people about the benefits of a scientific society. It seems paradoxical that a world which has been profoundly transformed by science, primarily through the face of technology, exhibits a growing unease about the benefits of such a world. What was worrisome in terms of the effects of technology, including super efficient weapons of war, has now become a worry about the psychological effect of science.

This growing unease about where the scientific world is taking us, something which the scientific community does not seem to take much note of, has emboldened people to be more exploratory about other possible ways of living their lives. Religion has never vanished from the consciousness of people in any culture (what better

illustration than the regeneration of religion in Russia after glasnost) but what it needed, especially when confronted with the powerful antagonism of science, was a gap in the fence through which it could again assert itself. Today it is beginning to do so and is taking a lesson from science itself to do it: by appropriating scientific terms in order to describe itself.

But, at the heart of it, the conflict between religion and science is for the soul of the individual. Paradoxically, both these groups have a problem with engaging with the individual. For science, it is the collective that is essential and for religion, it is the transcendent which is of importance. Both of them manipulate and mutilate the individual in their search for what they consider as truth. While much has been written about religion's role in this, there has not been enough of a reflection on how science also participates in this activity. Science's engagement with ethics well illustrates this problematical relationship with the human individual. Ethics is itself at the boundary between science and religion. In traditional societies, it was religion that supplied rules of ethical behaviour. In contrast, modern science becomes possible only when science gets rid of the ethical burden on scientific thought and action. How this happens is a fascinating story and well exemplifies the institutional and political character of science.

Although I have been using the word 'religion' as if it is a homogenous idea, it is not really so. There are significant differences in the way different religions approach science. While the comments about appropriation of scientific terms in religious discourse is common to major religions like Hinduism, Buddhism, Christianity and Islam, there are also differences in the way these religions have responded to modern science. Many of the characteristics I mentioned above are true for religious institutions, those that compete with science in the social and political arena and so is true for Christianity as well as Hinduism. At a cultural level, there are other more intriguing relations between religion and science, particularly in India.

I will briefly allude to these interesting relations between science and religion in the Indian context. Perhaps paradigmatic of this relation is the often cited story of how space scientists in India offer prayers in major temples before the launch of their satellites and space vehicles. There are well-documented reports of how one group of scientists from the Indian Space Research Organization (ISRO) takes the model of their satellites to a temple in Karnataka for prayers before the launch of these satellites. Scientists from ISRO also take models of satellites to the Tirupati temple, arguably the most powerful temple in India, before the launch of their space vehicles. As recently as the summer of 2010, the Chairman of ISRO was reported to have gone with a group of scientists to this temple for prayers before launch.

There is a cultural festival followed by the Hindus in India called the Ayudha Pooja (Sarukkai 2008). This is a festival on which 'prayers' are offered to machines (an extension of the original practice of offering prayers to weapons). In today's world, machines include not only computers but also many scientific apparatus. What is remarkable is that many if not all of the leading scientific institutions in India today follow this custom where prayer is 'offered' to these machines by anointing sandal and other marks on the machines, placing flowers on them and doing other acts related to worship. This practice has become so endemic in India that worshipping vehicles has become an important component of temple worship. There are temples (and specific divine beings) which specially cater to these needs. One can see huge crowd of all kinds of vehicles ranging from scooters to trucks waiting for 'worship' to be performed on them by the priest. As a matter of practice, all new vehicles get a worship of this kind.

One may very quickly dub these acts by scientists as well as non-scientists as acts of blind belief and superstition but I think that this misses the point as to why these acts have become so integral to Indian cultures. First of all, these ways of responding to vehicles and machines are not restricted to mainstream Hinduism. These acts

primarily illustrate a complex relation between science and religion in the Indian religious context, and have important consequences on how technology is understood by a culture. One such problematic consequence is related to the ethics of science and technology.

Science and the Ethics of Curiosity: The Troubled Relationship

What does ethics have to do with science? After all, for over centuries there has been a sustained belief that science is not answerable to ethical concerns. Science as a specific kind of activity (and discourse) is often seen to be independent of ethics. This belief is so much ingrained into the science community that even today prominent scientists as well as students of science echo the belief that science only discovers truths and the ethical is only in the context of how the products of science are used or misused. The most common example is that of the knife: a knife is used to kill but it is also used for other useful purposes. When used to kill, one should not blame science (as far as the knife is seen as a product of science). This is an oft-repeated argument for shifting the ethical responsibility from science to the larger set of users of science – this might include the ordinary citizen as well as governments. In doing so, what is reiterated is the fact that the truths of science are transcendental truths, outside human interests and therefore, outside ethical concerns.

The philosophers supply ammunition to this position by distinguishing between facts and values, a distinction that has a long intellectual history. This philosophical distinction offers one possible way to argue for science's independence from ethics. Science is a discourse of facts – facts about the universe. Ethics is about values – values held by humans. Scientific truth and facts are not human-centric. In fact, their exalted status arises primarily because they are thought to be independent of human subjects and thus it is reasonable to expect that they are not concerned with ethics. This distinction is reinforced by what is called the 'naturalistic fallacy' by philosophers. This is the fallacy of confusing the world of facts and values, the 'is' with 'ought'. The world of 'is' is the world of facts and

the world of 'ought' is the world of normative ethics. How one ought to behave is an ethical question whereas how the world is is a matter for science.

But, even if subscribe to the view that facts and values should not be conflated, there is still a problem for the science-ethics relation. Science is not merely a descriptive enterprise. It does not just list out the facts of the universe. Science is as much about intervention as it is about description. In fact, explanation, which is an important category for modern science, is privileged in science because it affords a greater control over intervention in the world. In other words, science understands the world in order to intervene in it, to 're-form' the world to suit our needs and desires. Many contemporary discussions on ethics and science – for example, the ethics of cloning and stem cell research – centre around this interventionist strategy of science.

By intervening in the world, scientists deflect the question of ethics from the 'pure' to the 'applied' domain. The creation of these two categories of the pure and applied is itself an interesting move within the sciences. Pure science is often placed in 'opposition' to applied science (including engineering). The privilege given to pure sciences has had significant impact on the growth of scientific institutions. The hierarchy in which the pure is 'above' the applied is commonly reflected in the practice of science even today.

How is this distinction tenable? One way to understand this distinction is by invoking the idea of 'disinterestedness'. This idea has been used by philosophers in effective ways. For example, Kant uses this idea as a defining marker in his definition of art. Disinterestedness is another way of expressing the absence of human interests in any belief or claim. It also suggests lack of prior motivation, 'ulterior motives', in doing something. The claim is that pure science reflects this disinterestedness. Its discoveries are about the way the world is and therefore cannot be influenced by human interests and desires. Pure science captures this character of science that it uncovers a set of human-independent truths. Applied science is application of these discoveries and scientists do not have much trouble in accepting that

such applications can be influenced by individuals, state, religion and so on.

The very distinction of the pure and applied is already value-laden. The usual opposites of pure are 'impure', 'contaminated', and so on. Applied is not exactly contrary to pure but has elements of these contraries. The value given to the image of pure is indeed very significant – purity is associated with the mind in certain states, to austere practices of the body, to high ethical action, to individuals who perform certain heroic acts and so on. Pure has high ethical value in religious systems. It has similar value even in areas such as chemistry where the isolation of the pure substance can be a worthwhile challenge. Racially, the idea of the pure has significant connotations and has spawned various fundamentalist challenges to society. It is in this larger world of the 'pure' that 'pure science' should be located. Given this trajectory of the pure, the word 'applied' in 'applied science' may have pejorative connotations. Applied is somewhat 'impure' – the taint or the contamination comes from the mixing of human interests in what is pure knowledge. The value to the applied is the value of materiality and not the value of disinterested inquiry. This also means that pure in the pure sciences does an important job for science – it keeps pure science out of the concern of ethics. Pure science is seen to be above ethical challenges. It is not that the claims of pure sciences are ethically sound or unsound; it is that they are not answerable to ethics first of all. If ethics is applicable to science at all then it must be in the domain of applied science – this is the commonly voiced claim about science in the context of ethics. This argument is so pervasive that scientists commonly use this for ethical questions on a whole range of issues ranging from uses of knife to nuclear energy/bomb.

It is striking that even in an essay published as recently as 2006 (and republished in an edited book in 2007) a scientist, Mario Bunge, rehashes the same argument. For example, the first section in this essay is titled "Do not blame scientists: Frisk technologists". Here Bunge continues the problematic distinction between basic and

applied sciences and notes that 'basic science, which is the attempt to understand the world, was mistakenly attributed the power to change it.' He continues to echo the most prevalent cliché about science and ethics in saying that 'technology can be used by industry or government for either good or evil nuclear engineering, which is based on nuclear physics, can be used either to design nuclear plants or nuclear bombs.' He goes on to title the next section as 'The ethics of basic science' where he reiterates the convenient distinction by noting that 'basic scientists' (who work on basic science) need have 'no such scruples' (ethical ones which might afflict the technologist) because 'his work is unlikely to have practical uses.' He also notes that basic science is characterized by a particular ethos. Following Merton, he lists the elements of this ethos as consisting of 'intellectual honesty, integrity, epistemic communism, organized scepticism, disinterestedness, impersonality, and universality.' All these are virtues which underlie basic or pure science. The interchangeablity of 'basic' and 'pure' is explicitly expressed by him when he notes that 'basic science is pure, but individual scientists may get corrupted.' These scientists get corrupted 'when given the opportunity to double as either technologists or policy consultants'! He further goes on to add that "[B]asic research is the search for truth, not for wealth, justice, salvation, or beauty.'

Bunge is not alone in his beliefs about basic/pure science and its ethos. Countless scientists place enormous emphasis on these beliefs although it seems obvious that there is little that is pure about pure science. The rewards of doing pure science is also material – witness the human drama around claims of originality, authorship, politicking for getting prizes and so on. None of these motivations are disinterested! But the reason why this distinction continues to be so important today is that there is an underlying ideology in insisting on this distinction as well as celebrating the ethos of the pure. I believe that this distinction and the invocation of the pure is primarily the most effective way of deflecting ethical concerns addressable to science. Scientists take this position so that they can

escape from the ethical imperative and in so doing are exhibiting their political agenda of safeguarding their work against pressures of the larger society. The fact that they have managed to escape from answering to the ethical challenge so far illustrates the effectiveness of this ideology.

In this paper I will consider one essential catalyst for this distinction. While disinterestedness and other such characteristics are markers of pure science, they are all based on a human capacity, the capacity for curiosity. Many influential narratives on science by scientists describing why they do science identify the nature of curiosity as a primal characteristic of the scientific attitude. Curiosity is a special faculty of the mind. Curiosity is not reason; rather, it needs reason to sustain it. Curiosity is what is common to the child and to the scientist, leading psychologists and philosophers to find parallels between a scientist and being a child. This is a position that finds strong resonance among practicing scientists and contributes to the distance between ethics and science for children can be excused from ethical excesses. Science uses the notion of curiosity to build a wall against ethical criticisms. Therefore, I believe that a proper ethical foundation for science can be developed only if we first understand the ethics of curiosity. But before we do that, we need to consider the ways by which science and ethics are coming together in recent times.

Putting science into ethics: naturalized ethics and the use of scientific method in ethics

The shift in ethics towards science has two dominant paths. One is through biology and this is by situating ethics in biological foundations. That is, we can understand our moral impulses as biological imperatives. Just as the natural processes of our body are dictated by the 'laws' of biology as well as explained by biological processes, so too can we understand morality as somehow related to biological traits and processes. In a sense, this makes morality 'natural', which counters an excessive dependence on culture as the

driving force of morality. Central to this biological understanding of morality is the argument that ethics is a product of a 'long evolutionary process'. The claim that ethics is part of evolutionary process implies that ethical principles and rules will help us in survival and adaptation. This belief that ethics can be traced back to biological and evolutionary roots is often called the naturalistic approach. Kurtz (2007a), for example, goes to the extent to say that the potentialities for good and evil have a genetic basis but goes on to note that what an individual eventually becomes depends on various influences. Some biologists have argued for viewing morality as a biological process. For example, it is suggested that human evolution has led to the capacity of human intellect. Calne (2007), speaking from the perspective of biology, suggests that our capacity for reason and morality are biological products of evolution. He argues that reason (equivalently for him, science) and social behaviour (equivalently morality) 'evolved together as the primate brain enlarged.' He points out that damage to the frontal lobes can impair both rational activity as well as moral decisions.

There is another way of approaching the science-ethics relation. Once again this has been championed by those who believe in the epistemological primacy of science. The basic idea in this view is as follows. Moral principles and values are often dictated by religion, politics, ideologies and so on. There is a fundamental difference in these activities when compared to science. What distinguishes science is the scientific method, one which opens every belief to 'rational' evaluation. Thus, moral values should also be 'open to scientific evaluation'. What can scientific evaluation do to values? Kurtz argues that moral knowledge justified in this scientific sense will lead to 'wiser decisions', those based on 'scientific evidence'. The basic argument here is that we should use scientific method to help us make ethically 'reasonable choices'. Given a moral rule on how we should act, that rule should be subjected to a scientific analysis, meaning that the statement should be answerable to evidence and reason, understood in the scientific sense. Ethical knowledge should

thus be evaluated like scientific knowledge and therefore is open to change if needed. As Kurtz notes, for the naturalists, 'scientific inquiry enables us to revise our values and principles, if need be, and/or to develop, where appropriate, new ones.'

Kurtz accepts that there are 'general principles of right conduct' drawn from our cultural experiences, including basic norms in societies. The challenge in ethics has been to interpret general rules in specific contexts. So, even a statement that one shall not kill has to be interpreted in various contexts: that one can kill animals, can kill in self-defence, can kill in war and so on. Kurtz believes that scientific inquiry comes into play when we consider general ethical principles in specific contexts. How we should deploy these principles in 'practice depends on the context at hand, and the most reliable guide for mature persons is cognitive inquiry and deliberation.' He concludes by noting that 'ethical naturalism attempts to solve ethical questions, not by faith or feeling but by empirical methods and cognitive inquiry.'

But such a view is possible only if there is a limited interpretation of both science and ethics. Kurtz wants inquiry to replace faith but understanding ethical judgements as based on faith alone is to be ignorant of a large philosophical tradition of ethics. Trying to suggest that 'education and persuasion' (as part of this scientific ethics) should replace 'violence' is once again to gratuitously associate ethics with violence. Once again this is a complete misreading, for anybody who has studied the history and sociology of violence will remember science's essential involvement with violence in diverse ways. Such a view also negates very important ethical theories developed in other parts of the world, which have found an intrinsic connection between non-violence and ethics. For example, the Buddhist and the Jaina traditions exemplify ethics based on non-violence. In contemporary times, Gandhi stands out as the most important thinker whose ethics is based on the idea of non-violence. Moreover, the strength of naturalistic ethics, namely, the use of inquiry, rationality, evidence, contextual deliberation and so on are integral

parts of these traditional ethical theories based on non-violence and sacrifice. The fact that Kurtz seems to completely negate these ethical movements is only evidence (in the scientific sense!) that these ideas of science and ethics are completely localized to a specific Western mindset. Such selective misreading of ethics as well as of the nature of science is definitely not part of the ideal scientific methods which Kurtz and others espouse.

Kant's attempt to ground morality in rationality is well known. What Kant is doing is to base the imperative of moral action on our essential rationality. Kant's rationality is also one that has significant overlap with (and influenced by) scientific rationality. I mention this only in order to point out that claims that ethics needs inquiry is not new to the discourse on ethics nor is it necessary that science is needed to do this job. Moreover, the scientific notions of evidence and reason, for example, are not universally valid across all domains. These notions which underlie scientific inquiry have specific characteristics which do not allow their easy access in other disciplines including ethics. Their use even in the disciplines constituting social sciences has been very contentious.

Another possibility to find a science-ethics relation is by choosing a different metaphysics. Rottschaefer (2007) offers an analysis of how a 'scientific naturalistic ethics' is possible. For him, this means the acceptance of moral facts 'that partially explain what makes action morally right'. The idea of moral facts or moral properties is similar to that of scientific properties. Among other things, scientific properties describe a causal sequence of some phenomena. In the same way, if there are moral facts or properties, then they can be used to causally explain a moral action. Those who insist that ethics and science are essentially distinct would find the invocation of moral properties and facts to be problematical.

Rottschaefer accepts that science is not only about facts. He distinguishes science and ethics by pointing out that science is 'concerned with cognitive values and ethics with moral values'. For the separatists, these values are distinct and thus ethics and science

are essentially separate. The Integrationists deny this separation of these values associated with the cognitive and the moral. The denial of the distinction leads to two distinct streams: one in which the methodological distinction itself disappears leading to the 'subjectivization of science' and the other in which the methodology common to both ethics and science is based on cognitive values thus leading to 'objectivization of ethics'. Rottschaefer identifies seven hypotheses relating ethics and biology (and psychology). These hypotheses are about how biological and psychological correlates provide facts, explain moral action, generate normative moral principles, justify moral beliefs and so on. His motivation is to establish a naturalistic account of moral values, that is, to ground moral action in natural moral values as facts which have explanatory capacity to explain moral action, leading to the view that 'ethics is a moral science'. This ontological approach where the role of moral facts is important, as well as the epistemological approach of explanatory structures, are brought together in order to argue for a naturalistic ethics.

Virtue epistemology

A philosophical response to the above problems illustrates yet another way of relating science and ethics. Over the last two to three decades there is increased interest in a new approach to epistemology which is called as virtue epistemology. The basic insight in this approach is that epistemology and virtue theory are intrinsically related. Terms such as duty (epistemic duty), responsibility, good etc., are essential part of epistemology and these terms are derived from the discourse of morality. The distinction between fact and value is challenged in these approaches. Typically, virtue epistemologists – and there are different strands within them – focus on values and virtues. They understand the evaluation of an epistemological claim by not restricting themselves to acts or belief states but to virtues in the person who is involved in the process of knowing. By bringing back the notion of 'intellectual virtue' to prominence, the virtue

epistemologists expand the ways by which we understand the notions of justification, belief formation and so on.

An implication of such an approach is to accept that epistemology is not just about abstract belief or propositional states but to see it as essentially socialized. This means that the knowing subject and the environment in which the subject functions are essential parts of evaluating knowledge claims. Traditional epistemology – especially where modern science was an exemplary model – was based on the negation of the knowing subject in evaluation of knowledge claims. Virtue epistemology brings back the knowing subject and the sociality of this subject as an important element of the knowing process. Virtue epistemology claims that intellectual virtues such as impartiality, intellectual sobriety, courage, curiosity, being truthful, sensitivity to detail, intellectual humility, fairness in evaluating the arguments of others, intellectual perseverance etc., are essential to the process of knowing. Moreover, analysis of problematical but crucially important concepts, such as understanding and wisdom which are problematic for traditional epistemology, is central to virtue epistemology.

Bringing virtues into the heart of knowledge, is to erase the distinction between the is and ought, between fact and value. It is to say, albeit in a different way than some other arguments which make similar claims, that facts are value-laden and values are fact-laden. This distinction between fact and value has often been used to negate any ethical questions addressed to science since science was seen to be the domain of facts and ethics the domain of values. Virtue epistemology, without being as scientistic as naturalistic ethics, allow us to understand that scientific knowledge shares a common space with ethics.

One of the most important intellectual virtues is curiosity. It is interesting to note that this idea of curiosity is also one that is very privileged by scientists and mathematicians. The heart of science, as scientists have often told us over the centuries, is curiosity. A scientist is defined by her capacity to be curious and in so doing

embodies the virtues of a child. The virtue epistemologists' emphasis on curiosity as an intellectual virtue as well as the scientists' emphasis on curiosity as an essential catalyst (and marker) of science marks an interesting conjunction of ideas. This is ironical since the scientists' use of curiosity, as we will see below, is primarily to escape any ethical responsibility whereas for the virtue epistemologists curiosity as a virtue should be understood within the discourse of virtue ethics. Much harm has been done by science in the name of curiosity and thus if there has to be any legitimate ethical response to science it has to begin with curiosity. To really establish any useful ethical interrogation of science we have to begin by understanding the nature of curiosity.

Science and curiosity

Why does one do science? Why do scientists say they do science? What attracts them to that activity as compared to other activities? In popular discourses on science, particularly by scientists, there is much emphasis placed on the excitement of doing science at the individual level. The description of this excitement is often in terms of notions such as awe, the pleasure of discovering something new, satiating curiosity, engaging with something beautiful and so on. Many of these characteristics are derivative to a primary characteristic of the human mind, one which is very influential in the original drive towards doing science. And this characteristic is that of human curiosity. One begins to do science merely because one is curious. Curiosity is a very important element of being human. Although ubiquitous, it is not easy to understand the nature of curiosity.

Curiosity is seen to be the catalyst that creates knowledge. Because we are curious we think. Because we are dissatisfied with the answers we get, we come up with new ways of thinking. Because we are curious, we discover methods. We discover science. We can distinguish – loosely – different types of curiosity. We may be curious about what something is – for example, I see an object I have not seen before and I am curious to know 'what' the object

is. We are curious to know why something is the case – why is the sky blue? Why is the neighbour's door locked all the time? We are curious about how something works. Experimental science is based so much on the character of curiosity – our first engagement with tools and technological objects is often one of curiosity. For example, an experiment was conducted in Delhi which involved keeping a computer in a hole in the wall in a locality where slum children lived. Rather than teaching them computers formally, these children were exposed to the computer to do what they wanted. Remarkably, the children learnt many aspects of the computer and they did so because they were driven by curiosity.

Curiosity is so pervasive but there is often a suspicion attached to excessive curiosity. The phrase 'Curiosity killed the cat' is widely used. Often we caution children not to be 'over-curious'. Children exhibit a stronger sense of curiosity which seems to diminish as we grow older. This trend often fails in the case of good scientists. The image of the ideal scientist is one who is eternally curious – this should remind us of the pervasive view that scientists are 'child-like'.

The beliefs about science and curiosity are many and deeply ingrained in the scientific community. Some of these well-entrenched beliefs are: science begins from curiosity, curiosity is the catalyst for pure science, scientists even when they are old should not lose their curiosity, questioning attitude comes through retaining the spirit of curiosity, science is where 'curiosity is institutionalised' and so on. Einstein echoes what countless scientists say:

> 'The important thing is not to stop questioning. Curiosity has its own reason for existing. One cannot help but be in awe when he contemplates the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of this mystery every day. Never lose a holy curiosity.'

Curiosity is often seen as being synonymous with the questioning attitude. Here it is worthwhile to distinguish between curiosity and

doubt. Doubt is an epistemological term – it is derivative to something more basic such as perception. I see an object which looks like a man but because it is some distance away I am not sure whether it is a tree or whether it could be a tall man. This creates doubt in me and I have a question concerning that doubt. Doubt also can be classified into types of doubt – like curiosity, we have doubt about what something is, why something is the case, how something works and so on. But doubt is not a human trait that is basic in the way curiosity is seen to be. It is not because we doubt that we ask these questions – doubt is based on some judgements we make about our perception and inference. But doubt, like curiosity, is what leads us to questions and also to knowledge. However, curiosity is a psychological act and not an epistemological one. That is, curiosity is 'biological' – the fact that some people are more curious than others is like saying some people have better eyesight than others. But all have eyesight and all of us have the capacity for curiosity. Doubt is a higher order term in this sense.

But interestingly, curiosity was not always held in high esteem. Phrases such as 'nosy parker', 'morbid curiosity', 'curiosity kills the cat' captured the potential problems inherent in curiosity. Being curious is also to be too nosy, interfering in matters where one is not supposed to, not minding one's business, being too inquisitive and so on. Stories in different cultures often are unsympathetic to characters who are too curious. In Western thought, the impact of the myth of Pandora's box and what it says about curiosity are well known. The influential *The Golden Ass* by Apuleius illustrates the danger of being overly inquisitive which leads to disastrous consequences. Apuleius is, according to Walsh (1988), responsible for the popular use of the word 'curiositas'. The main character in the novel is punished not only for being curious but also for insisting on satisfying his curiosity. A similar parallel occurs in the narrative of the folk tale of Psyche and Cupid. Psyche pays an enduring price for her 'rash' curiosity but eventually is saved by Cupid who says that 'Once again, poor girl, that same curiosity was your undoing' (Walsh 1988). In

this case, curiosity as a means to knowledge becomes problematical when a person not eligible for a particular knowledge tries to attain it through his or her curiosity. (It is interesting that Indian stories do not seem to emphasize the negative aspects of curiosity as the Western traditions do. There are a few stories such as Kunti's curiosity which leads her to becoming an unwed mother but on the whole there is definitely a cultural difference in the way this idea has been used in these cultures.)

Walsh discusses various senses of the idea of curiosity starting from Plutarch, who discusses undue curiosity in individuals. Plutarch was worried about the effect of curiosity on social habits such as prying into the affairs of neighbours, 'their debts, and their private conversations'. Plutarch then goes onto distinguish two ways of responding to the impulse of inquisitiveness. One is to avoid temptation to be inquisitive when it comes to social behaviour. The other is to direct our curiosity towards nature – heavens, earth and sea. Plutarch's solution to the problem of curiosity is to distinguish 'vulgar' curiosity and the more lofty 'intellectual' curiosity. Thus, development of 'intellectual' curiosity, which later on becomes so important in the activity of science, should be cultivated against the tendency towards vulgar curiosity.

The emphasis on intellectual curiosity was also of great interest to Augustine. Seneca believed that curiosity about nature was a positive virtue and it is interesting to see why – for Seneca this kind of curiosity is justified because such curiosity towards the world adds to our understanding of the value of human life and therefore can be seen as a 'moral pursuit'. Curiosity of this kind, one which gets valorized in scientific curiosity, had this intrinsic moral character at least in the early Western tradition. (In contrast, such curiosity that characterizes modern science has completely been excluded from the ambit of morality.) As Walsh notes, the Aristotelian tradition supported disinterested inquiry whereas the Stoics argued that such curiosity was justified only if increases virtue.

By the time of Augustine we can see an established ideological

use of 'curiosity'. For the Christian tradition, curiosity was always problematic – even the fall of Adam and Eve is also due to their curiosity. For Augustine, attaining knowledge through means other than (and contrary to) the Bible was seen to be work of 'misplaced' curiosity, 'abominable' curiosity, 'impious' curiosity and the like. Walsh suggests that *The Golden Ass* had a significant influence on Augustine's *Confessions*. A common theme of importance in both is the significance of curiosity. For Augustine, curiosity was part of the process which led him to follow false trails before 'submitting to Christian baptism' (Wash 1988). For Augustine, the curiosity of vision is vulgar whereas that of the mind is disordered. Among the three vices he notes, curiosity is one along with pride and lust. Also, the suspicion towards the dark arts like magic was encoded in these arts being called as 'the curious arts' (Harrison 2001). Augustine uses the image of lust to describe the acts of curiosity such as curiosity being a 'lust for experimenting and knowing.' He calls curiosity the 'lust of the eyes' but we should note the implications of a 'lust of the mind' which is inherent in this view.

Given Augustine's influence on theology and ethics, it should not be a surprise to discover the impact of his views on curiosity. The medieval theologians continued this distrust of curiosity and along with magic, pagan religions, necromancy, they attacked astrology (which was becoming popular) as an activity which was catalysed by curiosity. Even Aquinas, although accepting the study of nature, retained curiosity in the list of vices. The condemnation of curiosity was wide-spread, from the Renaissance and Reformation to the age of Puritanism in late 16th and 17th century in England. As Harrison points out, these views on curiosity were 'not restricted to moralists and divines, and allusions to this intellectual vice abound in the works of seventeenth-century poets, prose writers, and dramatists' (Harrison 2001). Similar to earlier views on curiosity, the strongest vice associated with curiosity was pride, the 'deadly sin'. Harrison notes how Downame (17th century) claimed that pride and curiosity were in a cyclic relation. Pride was the mother of curiosity and at

the same time, curiosity led to vain knowledge which increased (or 'puffed-up', a term that begins to get used widely around this time) one's pride. By the seventeenth century, methods of inquiry were subjected to ethical analysis and thus each method of analysis came to be associated with virtues or vices as the case may be. If certain methods of knowing and inquiry were associated with vices such as curiosity, vanity and so on, then it also meant that knowledge acquired through such inquiry was contaminated by these vices.

Not only were astrology and alchemy seen to be the 'dubious fruits of curiosity' but so were subjects like mathematics and the mechanical arts in the Renaissance 'associated with the proscribed practices of witchcraft and magic.' There is a common structure that can be discerned in this suspicion towards curiosity. Dominant is the recognition that there is a dual aspect to curiosity – 'the moral status of the inquirer and the nature of the proposed knowledge' (Harrison 2001). This explicit invocation of the moral status of the inquirer and also the nature of knowledge derived from curiosity are important elements of any ethical response to curiosity.

This suspicion towards vain/pure curiosity and knowledge about the world, one can imagine, must have constituted a grave challenge to the birth of modern science where both these characteristics are essential. Francis Bacon is often referred to as a very important figure in the establishment of science. In this story of curiosity, he also plays an important role. Bacon begins by distinguishing knowledge about the world and vain curiosity which he relates to magic, alchemy and the like. He then argues for the usefulness of knowledge about the world by relating it to the ethical virtue of charity. Thus he shifts the association of knowledge with pride, curiosity etc., to a seminal Christian virtue, namely, charity. More significantly, he cleverly established the legitimacy of studying nature by two arguments – one, by showing how such effort is consistent with biblical interpretation and the other by denying that knowledge acquisition is not morally wrong if done properly. There is a moral connotation to this proper conduct and thus doing natural philosophy (science

for us) necessitated 'certain moral qualifications'. Consider some of these qualifications: purity of the mind with respect to motives, restricting intellectual lust and 'tendency to excess'. In place of 'lust and gluttony' (with respect to the mind) he suggests 'abstinence and chastity' for proper intellectual activity. As Harrison notes, this is an ascetic model of seeking knowledge, elements of which are present in today's narratives about working in science, which includes giving up (or at least have restrained indulgence in) the pleasures of the world, a disciplined and sustained mental perseverance and so on. For Bacon 'it is charity that must motivate the knower, not curiosity.' Therefore, Bacon makes possible the pursuit of science in a way that is acceptable to the larger society by placing knowledge within the sphere of accepted morality as well as erasing negative views on curiosity.

From the seventeenth century positive values get attached to curiosity. Hobbes characterized curiosity as a 'morally neutral "appetite of knowledge"'. Hobbes also used curiosity to distinguish humans from animals and thus puts curiosity in a constellation of ideas such as rationality which served to make this distinction in Aristotle. For Hobbes and Descartes, curiosity was the origin of the search for knowledge. For Descartes, the problem was in unmethodological curiosity and so he constructs method which will control 'blind curiosity'. Over the course of the seventeenth century, curiosity gets established as something natural, something innate which characterizes human thought and action. It is not an accident that this period also saw the invocation of duty towards attaining knowledge. No longer was knowledge to be an idle pastime or even something belonging to the curious and evil arts but was now the beholden duty of the intellectual to pursue. But even when curiosity is accepted as a natural part of being human, it was also felt that its purpose was to 'seek out moral regularities in nature.'

Harrison also briefly discusses how curiosity is legitimized by relating it to the Divine. Robert Boyle, among others, looked at nature as embodying various curious features. Curiosity is thus

removed from being a particular human proclivity to being something which characterizes features in the world, features which excite our curiosity perhaps. (Something similar happens with various other subjective concepts such as beauty, which over time gets removed from a particular psychological response to a 'property' inherent in beautiful objects.) If curiosity now characterizes the world (so that we can talk about 'curious creatures', 'curious objects', 'curious features in an insect' and so on) and if the world is created by God then the negative value associated with curiosity is negated – this argument of Harrison has some force.

By the eighteenth century curiosity was completely 'rehabilitated'. David Hume's definition of curiosity as 'love of truth' was part of this process where curiosity, like in the case of Descartes, was the genesis of knowledge. Moreover, Hume also claimed that not being curious leads to ignorance and 'barbarism'. So not only is curiosity a positive virtue it is also one that is necessary for certain positive ends. As Harrison notes, '... if for Aristotle wonder was the beginning of knowledge, for Hume and his contemporaries that honor now fell to curiosity.' Harrison concludes by suggesting that the trajectory of the idea of curiosity also indicates a shift in the way the relation between the knower and the known was understood – earlier the moral character of the knower was important but this role of the knower loses its significance as the notion of curiosity achieves its positive status. In other words, the morality of the knower becomes less important as curiosity becomes more important to the extent that in modern science the morality of the scientist is completely erased in evaluating scientific knowledge. Thus, an impersonal method replaces the subjective knower – a trend which Harrison discovers not just in Descartes but also in Bacon and others. And over time and with increasing distance between Christianity and science, the idea of method dominates the view of science.

The creation of modern science was also the creation of new meanings for curiosity. The rehabilitation of curiosity as a positive term was essential to the development of modern science. Peters

(2001) points out how the changing meaning of curiosity was part of the discourse on exploration and discovery leading up to Columbus. Legitimizing travel to distant places, as well as exploration of the world – including exploration for commercial purposes such as mining – was necessary because travel and exploration were not always seen as positive acts. The recreation of the meaning of curiosity was used to validate such explorations and discovery of the secrets of the world. Part of this program of legitimization was related to the Church's attempt to take Christianity to the rest of the world.

Scientists were consciously aware of the changing discourse on curiosity and in fact worked towards promoting new meanings of curiosity. Perhaps the best illustration of this is in the way the Royal Society used curiosity in the eighteenth century (Costa 2002). For science, the validation of wanting to learn about new and strange phenomena rested on the idea of curiosity. The Royal Society in the first half of the eighteenth century contributed to the value of curiosity through various institutional means. In the communications presented to the Society, not only medical events but also astronomical ones were often described as being curious. As Costa notes, even the 'certificates of election presented to the Society also illustrate this 'language of curiosity'. For example, a certificate presented to Henry Stevens 'described him as 'gentleman of extensive curiosity'.' Costa argues that 'being curious' was promoted as an important trait of being a scientist and the 'pursuit of curiosities' as being a valuable act. The Society took it upon itself to promote this practice of curiosity - so there were 'regular exhibitions of natural and artificial curiosities at the meetings', members were encouraged to have their own collection of curiosities and it became a tradition for the Fellows to donate curiosities (Newton donated a 'small bird brought from Pennsylvania').

Curiosities played an important role not only in the activities of the Society but also in framing definitions of knowledge and science in the eighteenth century. Costa concludes by noting that the 'place of curiosities of nature at The Royal Society therefore shows the variety

and intricacy of elements involved in the making and diffusion of natural knowledge in the period.' In the latter eighteenth century the preoccupation on curiosities decreased but by then curiosity had been completely rehabilitated. In fact, one can already see this influence of scientific curiosity in literature. The most notable example is that of detective fiction. The detective story is often modelled on the scientific and has various instincts of the scientific in it. Edgar Allan Poe is often credited as being the author of the first modern detective novel (*Murders in the Rue Morgue*) – this novel 'presents itself as scientific' (Goulet 2005). Positive virtues of curiosity – including a passion for it as well as something which is a disinterested enquiry – have marked the history of the modern detective. The 'jargon of scientific enquiry' was a primary influence on fictional detectives and the rehabilitation of curiosity had an important role to play in this.

The discourse on pure and applied was also significantly changed in the changing history of curiosity. Justification of knowledge in the early phase was based on its moral and religious usefulness. But later the justification is in terms of practical use – a move which, Harrison argues, also establishes the distance between the morality of the knower and the known. Thus, the shifting notion of usefulness in the context of scientific knowledge meant that the moral status of the scientist is irrelevant to the claims of that knowledge – herein we can see the beginnings of the imposed expulsion of ethics from scientific practice. The very fact that we often use 'science' (as an impersonal discipline, a method) instead of 'scientist' even in contexts where human agency is clear is another indication of the success of this project of erasing the human from nature, the ethical from the scientific.

The trajectory of the development of the narrative about curiosity has important lessons about ethics and science. As Blumenberg (1985) points out, curiosity for Augustine was a 'temptation'. Curiosity today has come a long way from this view but in doing so has also divested any notion of responsibility. Among other positive virtues, it has come to be associated as a characteristic of children and also as a virtue related to innocence. It is this innocence of curiosity that

science shares with children and it is this innocence that is often the bulwark against insistent ethical questions towards science. It is this presumed innocence that makes scientists claim that their only duty is to discover 'truths', whatever be the consequence of such truths. Blumenberg's argument is that scientific revolution, as exhibited in the case of observations made by Galileo with his telescope, liberated curiosity from the clutches of a religious morality. This leads to the escape from 'self-restriction' which, for Blumenberg, catalysed the Enlightenment and the establishment of scientific method leading thereby to modern science. While this picture is perhaps too sweeping it is nevertheless true that the removal of 'self-restriction' was and continues to be extremely important to the practice of science. The belief that there should be no fetters to scientific *thinking* has its origins in this complex history.

The ethics of curiosity – Reinvesting responsibility in curiosity

The meaning of curiosity exhibits significant ambiguity. It has changed its meanings over the ages. There are a large number of terms that have been used synonymously and yet are not the same as curiosity: for example, in early modern period the following terms often overlapped the meaning of curiosity – wonder, marvels, admiration, interest, subtlety, rarity and so on (Evans and Marr 2005). Residues of this semantic spread are to be found even in contemporary uses of curiosity, particularly by science.

The scientific valorisation of curiosity and the freedom it entails (or *assumed* to entail) needs to be questioned if a meaningful ethics of science is at all to be possible. To do this, we need to relook at the notion of curiosity and exhibit its multi-layeredness. If science continues to invest heavily in curiosity then it should be answerable to these multiple meanings of curiosity. The very idea of curiosity is culturally mediated. It is part of a social process and is constructed to suit various ends of dominant communities, whether the religious or the scientific. Curiosity itself is value-laden with other virtues and vices. It is not restricted to the individual but is essentially social.

Curiosity is also a catalyst for action. We indulge in various kinds of acts because we are curious to see how something would feel, how a dish would taste and so on. The way children play with insects is a good example to understand how action is related to curiosity. Some children see an insect and might want to play with it. They are curious about various behavioural aspects of the insect. Inevitably, their curiosity gets the 'better' of them. They want to find out how the butterfly will fly if its wings are cut off, they are curious to see whether an ant will drown if dropped in a bowl of water, they are curious to see the reaction of dogs when they tie crackers on their tails and so on. To a great extent, these 'experiments' are driven by a sense of curiosity – a curiosity which is not regulated and which allows the children to do what they want in the name of curiosity to these creatures.

Scientific action is also many times significantly catalyzed by curiosity. They want to see at what temperature water will boil, they are curious whether a given element will conduct heat and electricity, curious about the melting temperature of objects and so on. Driven by this curiosity, they perform their experiments. They boil water, send electricity through an element and so on. The freedom to do as our curiosity dictates is the quintessence of doing science. In fact, we can see why the idea of pure curiosity is so essential to science because it is within this notion that the idea of freedom is contained. Pure curiosity is the scientific synonym for pure freedom, freedom without responsibilities, freedom without constraints. The model for this kind of freedom is the mind. While there are constraints on what a body can do or even what can be done to physical entities, there is nothing in principle to shackle our imagination, to regulate what the mind can think of.

However, ethics arises in order to control curiosity, among other things. When a scientist wants to test the limits of pain of a human being by subjecting the person to pain, we invoke ethics. We say that the curiosity of the scientist should be curtailed in this case. In modern ethical debates about science, particularly biology, the

primary reason why ethics is invoked is because it involves human beings (or in some cases life forms such as animals). Where a life form is concerned, ethics is invoked to constrain curiosity and its consequences. But what about other areas of science? What about a physicist's curiosity of how the universe is born or how stars collapse or what fundamental particles there are? Should curiosity in these cases also be constrained?

The answer is an unequivocal yes. The ethical question in science first occurs when we ask what constrains curiosity of any kind. The recent drama about the experiment in CERN is an indication of the need to control curiosity. Scientists are obviously curious to know about the Higgs particle. This experiment in CERN, where particle collisions will create energy of enormous magnitude, is an important one for science. It has the potential to satisfy the curiosity of the scientists about the origin of the universe, the Higgs particle and so on. But at what cost? Before this experiment, there were accounts of how some other physicists had predicted that a small black hole (with potential consequence of destroying the world) would be formed due to the high energy collision. While this claim was dismissed by the CERN scientists it leads us to wonder about the rights of a few scientists to explore their curiosity. Independent of the merits of the black hole argument, it nevertheless poses an ethical question to modern science. What price the curiosity of a small group of individuals? And who should pay it? Should there be limits to what they can explore knowing well that their curiosity can potentially destroy the world? But, on the other hand, the chance of it happening is very low. Although the problem here is that we have to take their word for it! How does one decide then? How do the scientists themselves decide individually on whether their search is worth the potential price? The question here is an ethical one but an ethical question whose subject matter is curiosity itself.

It is not only scientists who see curiosity as a virtue. Even philosophers have taken this position. For example, I discussed virtue epistemology earlier where curiosity is discussed as a virtue.

Baumgarten (2001) discusses how curiosity can be seen to be a positive and moral virtue. He offers an interesting perspective on curiosity and its relationship to care. 'Curiosity bears a close relationship to, and is often bound up with, care and concern. Curiosity is rooted linguistically in the other-regarding activities of "care" and "cure" (from the Latin *curare*, to take care of).' In human interactions, this element of care makes curiosity not a morbid one but one which is an important part of friendship. Moreover, curiosity is necessary for deepening one's friendship. Baumgarten believes that a similar process of curiosity towards non-humans, such as ecosystem or another's culture, strengthens the understanding of that object of curiosity. Therefore, he concludes that 'curiosity is a distinctive virtue which, compared to attentiveness and "being interested", more fully expresses human autonomy, plays a distinctive role in caring relationships, and enables us to learn about things we would not otherwise know.'

Curiosity can also have a deontological status. Baumgarten believes that it is our duty to be curious, a claim which should remind us of the scientific narrative about curiosity. However, in the fourth section of the paper he suggests that it is also a duty not to be curious in certain cases. Also, too much curiosity may be seen as a vice and not a positive virtue. So it leads him to consider morbid curiosity, debasing curiosity, voyeuristic curiosity as negative variants of curiosity. In the last section of his paper, he connects curiosity and living well: 'To say that curiosity is a virtue is to claim, most importantly, that it helps one to live well.' This is indeed a problematic addition to the idea of curiosity because what defines 'living well' is extremely contentious, particularly in the context of modern science and the development that it has entailed. Curiosity also does the job of supplying meaning in life and thus has an existential role. Baumgarten concludes by contrasting the religious suspicion towards curiosity as against secular notions of curiosity that emphasizes certain positive virtues but ends by saying that the richest life is one that combines the two.

This ambiguity present in any positive rendering of curiosity is but a natural consequence of the ambiguity present in the concept of curiosity. Trying to relate it to 'well-being' and 'caring' as Baumgarten does is very problematic, particularly for science's appropriation of curiosity. If curiosity towards nature is a fundamental impulse for science, then how is this curiosity related to the notion of care towards nature? On the contrary, curiosity in science often manifests itself in the most extreme forms of exploitation of nature. Furthermore, attempts to salvage curiosity by considering it as the element leading to well-being is also problematical since the definition of well-being is so different across different communities and cultures.

Thus, the fundamental problem is to come back to the ancient and medieval question about curiosity: how does one regulate it? For science which is very much dependent upon the idea of 'pure', unfettered curiosity, a regulated curiosity is undesirable. Regulating curiosity cannot just be normative. It cannot be regulated by religion or by the State. There has to be a self-regulative process in science, a self-restraint, if these ethical concerns are going to have any impact. And any 'self-ethical' move within science must first of all begin by asking what constitutes the boundaries of curiosity. About what are we allowed to be curious? At what point should we desist from being curious? And so on.

Interestingly, other cultures illustrate possibilities of understanding curiosity differently. Consider the Indian philosophical and religious tradition. Unlike the Western tradition, curiosity as a concept is not easily discovered either in ordinary language, or in myths or even in philosophical traditions. It is difficult to find a consistent narrative about the evil effects of curiosity like in the Greek and the Christian tradition. Doubt as a concept seems to be more prominent in Indian philosophical systems as compared to the notion of curiosity. Indian theories develop quite sophisticated analysis of doubt and doubt as a category is often associated with the origin of knowledge.

It is also quite difficult to find examples of pure curiosity. This is consistent with the general pragmatic and empirical worldview that influences various Indian traditions, including the traditions of philosophy and logic. Even mathematics in India did not make the shift to the kinds of formal, non-empirical systems that arose in Greek mathematics. Indian mathematics was essentially grounded in various empirical and practical concerns. Thus, a regulative element seems to be universally present in the Indian classical traditions. This presence of a regulative necessity places bounds on reason and desire – two elements so closely associated with curiosity. Even in the Western tradition, the criticism of curiosity is fundamentally about 'pure' curiosity or 'intellectual' curiosity but this kind of a 'pure' act is fundamentally not possible in the Indian worldview. Indian mathematics is not pure mathematics since it is essentially engaged with the world and nature; Indian logic is not pure logic since there are demands of the empirical which logical analysis has to incorporate in inferences; Indian metaphysics is not pure metaphysics since epistemological categories often get 'mixed' up with 'pure' metaphysical categories and so on. Bhattacharya (1958) discusses how in Indian philosophy 'ethics and metaphysics are inextricably connected.' The Indian traditions therefore exhibit the basic critique of the 'pure' in various activities. Perhaps this explains why the suspicion towards 'pure' curiosity was not so central to Indian thought as it was to the Christian tradition. But this also implies that the possibility of ethics is fundamentally ingrained into any activity since the normative is essential to every kind of physical, intellectual or spiritual act.

But given the hegemony of Western knowledge it might need lot more effort to make the case for alternate philosophical (including ethical) traditions to contribute to the discussion on ethics and science. In what follows, I would like to set out an argument which will allow us to establish an ethical critique of pure curiosity. First of all, a consequentialist approach will not help. One can argue that scientists should take ethical responsibility for the horrors of the nuclear bomb. Yet rarely scientists do so. The standard argument is that the bomb is not due to science but due to politicians and

others who take the decision to produce and then use the bomb. So negative consequences alone is not a sufficient reason for imposing ethical constraint on scientific activity since the scientists deflect the ethical component to other agents. In doing so, they also reify pure curiosity.

So what is the argument one can make about the dangers of pure curiosity – an argument that is not consequentialist alone? The first question we need to ask is this: who has the right to be curious? Under what conditions can we be curious? What can we be curious about? Who has the right to interrogate – whether it is other humans or nature? What are the necessary requirements before one can take on the role of an interrogator of nature?

We need to first recognize that various rights underlie every act that we do. And rights are granted to us (by the community) or taken by us (from the community). What we take to be an act of individual autonomy and personal choice is often one that is actually not only granted by the conditions but also only that is enabled by these conditions. That is, when we perform an act it is not only that there are no constraining conditions stopping us from doing it but there are also positive, enabling conditions that allow us to perform that act. And these enabling and non-constraining conditions are the contributions of other people, social structures and so on. Given that rights granted to us by others are an essential part of every act of ours then there is immediately a question of responsibility that is intrinsic to every act of an individual. Thus, social mores decide our behaviour in society and even in families. Everything that we do in a social setting is moderated and constrained by various factors.

Modern science – like art – reacts against this constant constraint imposed on us – whether they are constraints of nature or society. Morality arises in an attempt to curtail various desires of the body and as members of a community many of these constraints are accepted by scientists and artists also. What remained to be unfettered was the mind and while morality did attempt to find ethical constraints of the mind, it is far more difficult to regulate. For example, one could insist

that it is wrong to think certain kinds of thoughts. But it is difficult to know when a person indeed indulges in such thoughts unless he or she acts in a particular manner that exhibits these thoughts. Here, it is pertinent to remember that while art privileges the notion of freedom and self-expression, the importance of curiosity for artists seems to be very different as compared to scientists. Artists do not invoke the idea of unfettered curiosity to justify their activities. Thus, they are able to engage with creativity without using curiosity as a bulwark to protect them against ethical challenges. As an artist, K. V. Akshara pointed out to me, artists do not find a need to create an ideology out of curiosity. Instead, they create an ideology of pleasure to legitimize their work!

The freedom of the mind and therefore the freedom of the subject becomes a central issue for science and art. And among the first freedoms that are demanded is the freedom of expression and thought. But does freedom of expression mean that a person can say what he or she wants independent of the consequences? For proponents of freedom, this freedom is extremely important and even if one accepts a constraint on this freedom it can only be from the individual self. That is, there cannot be any external agent proscribing freedom of expression. But this means that at the same time there should be a sense of self-control in what we say. So even though we do not accept any external agent from stopping us in saying what we want, this full freedom of expression is then acceptable only if there is self-restraint.

What holds true for saying whatever we want also holds for thinking what we want and for being curious about what we want. Once curiosity is taken into the discourse of freedom and made a virtue of by science then it is indeed difficult to put external constraints on curiosity. Religion or philosophy cannot in principle put norms on the act of scientific thinking and doing. The constraints on curiosity have to come from within science. But the paradox is that science and scientists do not have the capacity or the interest to constrain their thoughts and actions especially since what justifies their activity

are these ideological values they ascribe to notions such as curiosity and freedom. So how then is this self-restraint possible? This can happen only through a dialogic process with other communities. Let me set out the argument for this.

Scientists are members of a larger society. Even if they want to project themselves as a special set of people involved in a special kind of activity, there is no possibility of science without it being seen as a part of a larger society. In most countries, science still continues to be under the patronage of the State. Modern states invest huge amounts of money into scientific institutions thereby enabling the activity of science. So should scientists be answerable to the society they belong to and which sustains their work? In what follows, I will only consider one aspect of this larger issue.

Consider the right to interrogate. In a society not everybody has the right to interrogate – lawyers can do so but only in a courtroom or under accepted conditions, police can do but only under constraining procedures, judges have the right but again only under certain conditions, parents want the right all the time with respect to their children but even they often have to follow certain said and unsaid norms.

In all these cases, nobody has the right to question without any accompanying constraints. Police, judges, lawyers, parents, colleagues – none of them have a right to be curious about another person without having inbuilt constraint on what they can ask, what they can explore and so on. In our society, everybody seems to have constraints – many of them being self-regulated – except for the scientists when it comes to curiosity about the world.

Thus, the first step in an ethics of science is to impose constraints on curiosity but this imposition cannot be done from outside, by other people but must be done internally, by the individual self of the scientist. There are many cases where this has happened. Individual scientists even today refuse to participate in certain kinds of research projects – for example, in defence projects, in nuclear projects and so on. These are constraints these individual scientists place upon

the nature of their work. However, they do not take the next step of constraining their curiosity per se.

And this is exactly what the scientists resist. For example, Kurtz (2007b) points out that scientific inquiry has always been under challenge from religion, politicians and so on. Today, he believes, the attempt to muzzle science comes in the guise of ethics. While he agrees that practical research and technology might need some kind of regulation he suggests that in the case of pure science there should be no such constraints. Thus, he says, in the 'area of knowledge and truth, I submit, *scientists ought, on utilitarian grounds, to be allowed to inquire as they see fit and to publish their results without the imposition of external standards of judgment as to the ethical worth of their investigations*' (italics in original). This statement betrays the ideological grounds on which science is possible. There is no independent definition of knowledge and truth. There are no activities in a society which are not under imposition of certain constraints. Hiding behind pure science and pure curiosity will not help. Scientists cannot be allowed to inquire 'as they see fit'. I am not talking about potential use of their results but the very mode of legitimate inquiry.

This argument might be construed to imply that scientists have no right to be curious and that once they lose this freedom of curiosity science will not be able to develop. It is not enough to say that scientists should not have unlimited freedom of curiosity. I would not want to take this line since it is then open to regulating intellectual activity by various vested interests. Instead, I suggest that the ethical basis of social communities lies in dialogue and negotiations. It lies in one set of people trying sincerely to convince the other members of the reasons for their action. Scientific curiosity has the most impact on a society – whether it is curiosity about what new features can be added in a cell phone to curiosity about the origins of the universe. Both these extremes do have material impact on the world.

Scientists have taken the easy way out when confronted with this

need to have responsibility. They have often projected themselves as an exclusive group and insist that the larger society cannot understand them. They are thus not only exclusive but also exclusionist. It is remarkable how so many scientists believe that they need not engage with society and establish a dialogue with the members of this larger society, which will include the religious, the non-religious, the sceptic and so on. Moreover, modern science has been dismissive of other different kinds of knowledge systems. It is dominantly Eurocentric in character. Thus, very well developed empirical knowledge as in Indian medical systems or even theoretical insights from Indian logic have all been arrogantly dismissed by modern science and scientists. Hundreds of such examples abound from all cultures in the world. Moreover, science is also paternalistic and patriarchal. It has embodied a very male view of the world and knowledge, as extensive literature in science studies and feminist studies have so well illustrated. Science has not shown the capacity to be inclusive, to seriously engage with other systems of knowing, to even consider philosophy seriously particularly in themes such as truth and reality, and so on. Until it is able to do all this it cannot demand the right to have free enquiry. As constituents of a society it has to practice restraints which are present on all members of the society.

In other words, the freedom to be curious is not a freedom at all. Nor is unbridled curiosity innocent nor is it really unbridled. There is nothing new in asking for responsibility in freedom. But what we should realize is that the first responsibility in science is not just towards specific scientific acts (such as whether there should be nuclear power, stem cell research and so on) but towards the very act of curiosity. There is little that is 'natural' about curiosity. Moreover it is never restricted to the individual. If science proves anything it is that curiosity is often manifested as a collective process. This is the curiosity related to research programs in a broad sense. In this sense, scientific curiosity is always 'social' curiosity. An integral component of such curiosity is the role of the social and that role is one of responsibility towards the members constituting the social.

Science and its Impact on the Self

There is yet another important dimension of science in the context of its relationship with society, namely, the dimension of development of a society and nation. Modern societies are deeply indebted to modern science for its growth and sustenance. Societies today are predominantly scientific and technological societies. Modern economic systems are basically dependent on scientific and technological development. The political strength of a nation state is crucially dependent on technologies associated with defence as well as the establishment of strong scientific institutions.

Indices of human development correlate scientific growth with growth of societies. The paradigm of development is often based on the establishment of large science and technological projects such as the dam, space and nuclear projects. Even the public discourse on modernity and development equates these with science and places science in opposition to tradition, religion and superstition.

On the other hand, there are many strong critics of the scientific model of development. But there has been much written on this and so I will not enter into this debate. Instead, to end this reflection on science and the human subject I will, perhaps a bit indulgently, discuss a particular impact on the human self caught within the eddies of contemporary scientific societies.

Speed is the theme of our society today. In an age defined by our desire for speed, nothing is enough. Everything we do falls short or is always less. In this age, we are always losing the race because that is the nature of speed. Earlier, one would be satisfied in doing one film a year or record one music album in a year or two. Earlier, doctors used to perform one or two surgeries in a leisurely manner. Today, the fame of doctors rests on how many simultaneous open heart surgeries they do. In days gone by, a writer would be happy with writing and then typing out one novel in a year or two if not more. But today if a novelist is not always in the limelight, always writing and publishing, she is immediately forgotten. A scientist cannot publish one or few papers in a year. To even survive in the

scientific community, speed of production is of utmost importance.

Human desire has found the right technological tools in this age to make all this possible. Today's technological culture is about speed, efficiency and control. Computers rapidly change, sometimes in a year or sometimes within a year. We have gone through many generations of computers within the last few years. Each time a new, higher speed chip is installed the old systems go obsolete. Our new desires for speed are built on the graveyard of indestructible machines.

Mobile technology and mobile phones change even more rapidly. They have become faster and more efficient in every sense of the term. Mobiles are now our place of residence. In earlier times, there were caravans which were called mobile homes. You could take your house along with you. Mobiles are exactly like the mobile homes except that we now carry our home in our hands. Sadly, humans have lost the use of one hand because everywhere people are carrying a mobile in that hand!

Mobiles, like computers, have gone way beyond their original intent. Mobiles are now not really about instant communication. They are home entertainment systems, they are cameras, they are computers, they are whatever you want them to be. Since everybody now carries their home with them there is really no private space. Mobile technology shows the nature of our life today: we are so much in a hurry, we have forgotten how to wait. Whether waiting in lines or waiting for our turn in life. We can't wait to go home and listen to the songs we like in the privacy of our rooms; instead, we want to hear it immediately and wherever we are. We have forgotten how to go slow, how to be like the tortoise.

There are important psychological and social consequences of living a life in this manner. First, is the constant anxiety that pervades us at every moment of our lives. These technologies – those which compress space and time in this manner – impact upon the way we live, the way we see the world and how we interact with people. The terrible anxiety which arises when a mobile is not answered, the

anger when a person does not 'return' the call, the irritation when there is no 'service' are all anxieties which affect the equanimity of individuals. The expectation that communication is instantaneous, that every email needs an instant reply, leads to constant expectation – not just from other individuals but even from anonymous organizations. This expectation and the anger that comes when this expectation is not fulfilled are products of desires. Desires are integral to many technological products.

Development, a term which has come to characterize all societies in this modern global world, is a term which is intrinsically related to speed of societies. Tradition is counterposed to this – most times wrongly. In our common understanding of tradition, we do associate it with lack of change, a kind of staticity. Rate of change of habits characterize social change.

Change at great speed, like it happens in our lives and societies, implies that we do not have enough time to correct a mistake if needed. It also implies that we do not have control over the change. The problem is not about change – after all, evolution of society is fundamentally one of change. The problem is only in the speed of change and in the control one has over that speed.

What then is the way out of this conundrum of living in a rapidly changing technological world which has serious consequences on our psyche? Often, we are told that this is a natural progression of human kind and that people should not resist the growth in science and technology. Perhaps there is something natural in this progression but there is nothing natural in the kinds of science and technology which characterizes modern science and technology. These are products of many kinds of forces ranging from market economy to waging war. Both capitalism and the 'project' of waging wars by nations have been the foundation stone for many technological innovations. The liberal economic as well as defence institutions have been major supporters of research in science and technology.

How do we respond to these issues? One way is to wish science and technology away but this does not seem to be a pragmatic path.

The other is to humanize science and technology in various ways. To humanize science is to bring back the human subject in its fullness within science and technology. It is to recognize that the project of science is just one project of humankind along with other activities such as literature, arts, music and so on. It is to recognize that along with one particular kind of reason, the reason associated with science, there are other forms including the rationality of art and spirituality, as well as that of many different human communities who have varied views on the nature of the world and the cosmos. Bringing all these activities together in a harmonious sense may seem like a utopian dream to some, undesirable to some others but I believe that this is the only way in which the future of humanity as well as the future of science can be harmonised.

References and Further Reading

For very good introduction to technology in ancient cultures, see:

Ada, Michael. 1989. *Machines as the Measure of Men.* Ithaca: Cornell University Press.

Alvares, C. 1991. *Decolonising History.* New York: The Apex Press.

Bhattacharya, K. 1958. "Classical Philosophies of India and the West." *Philosophy East and West* 8.

Sarukkai, Sundar. 2002. *Translating the World: Science and Language.* Lanham: University Press of America.

An original treatment of the history of non-Western civilizations in the development of modern science is:

Bala, Arun. 2006. *The Dialogue of Civilizations in the Birth of Modern Science.* New York: Palgrave Macmillan.

On the cultural impact of technology:

Sarukkai, Sundar. 2008. "Culture of Technology and ICTs", in *ICTs and Indian Social Change*, Eds. A. Saith et al, London and Delhi: Sage.

There is a significant amount of work on Indian science, both in the colonial and the post-colonial era. For example, see:

Raina, D & I. Habib. 2004. *Domesticating Modern Science: A Social History of Science and Culture in Colonial India.* Tulika Books.

Krishna V. V. 1992. "'The Colonial Model' and the emergence of national science in India, 1876-1920." In P Petirjean, C. Jami, AM Moulin (Eds). *Science and Empires: Historical Studies about Scientific Development and European Expansion.* Kluwer.

Prakash G. 1999. *Another Reason: Science and the Imagination of Modern India.* Princeton: Princeton University Press.

Visvanathan Shiv. 1997. *Carnival for Science: Essays on Science, Technology and Development.* Delhi: Oxford University Press.

For historical treatments of the subject of curiosity and the relationship between science and curiosity, see:

Baumgarten, Elias. 2001. "Curiosity as a Moral Virtue," *International Journal of Applied Philosophy*, 15.

Blumenberg, Hans. 1985. *The Legitimacy of the Modern Age.* Cambridge, USA: MIT Press.

Boyd, D. R. 1990. "The study of moral development: a bridge over the "is-ought" gap", in *The Moral Domain*, ed. T. E. Wren, Cambridge: MIT Press.

Calne, Donald. 2007. "The Common Ground between Science and Morality: A Biological Perspective", In *Science and Ethics.* P. Kurtz. (Ed.) New York: Prometheus Books.

Costa, Fontes Da. 2002. "The Culture of Curiosity at the Royal Society in the First Half of the Eighteenth Century." *Notes Rec. R. Soc. Lond.* 56 (2).

diCarlo, C and J. Teehan. 2007. "On the Naturalistic Fallacy: A Conceptual Basis for Evolutionary Ethics", In *Science and Ethics.* P. Kurtz. (Ed.) New York: Prometheus Books.

Dreyfus, Hubert. 1996. "The Current Relevance of Merleau-Ponty's Phenomenology of Embodiment." In *Perspectives on Embodiment*, Honi Haber and Gail Weiss (eds.). Routledge, New York and London.

Evans, Robert J. W. and A. Marr (Eds). 2005. *Curiosity and Wonder from the Renaissance to the Enlightenment.* Burlington: Ashgate.

Gopnik, Alison. 1996. "The Scientist as Child." *Philosophy of Science* 63.

Goulet, Andrea. 2005. "Curiosity's Killer Instinct: Bibliophilia and the Myth of the Rational Detective." *Yale French Studies* 108.

Harrison, Peter. 2001. "Curiosity, Forbidden Knowledge, and the Reformation of Natural Philosophy in Early Modern England", *Isis* 92.

Kurtz, Paul. 2007a. "What is the Relationship among Science, Reason, and Ethics?", In P. Kurtz. Ed. *Science and Ethics.* New York: Prometheus Books.

Kurtz, Paul. 2007b. "Freedom of Scientific Research", In *Science and Ethics*. P. Kurtz. (Ed.) New York: Prometheus Books.
McCarthy, T. 1999. "Enlightenment and the idea of public reason", in *Questioning Ethics: Contemporary Debates in Philosophy*, ed. R. Kearney and M. Dooley, London: Routledge.
Peters, Edward. 2001. "The Desire to Know the Secrets of the World." Journal of the History of Ideas 62 (4).
Posnock, Ross. 1991. *The Trial of Curiosity: Henry James, William James, and the Challenge of Modernity*. New York: Oxford University Press.
Rottschaefer, William. 2007. "Scientific Naturalistic Ethics: Weird Science and Pseudo-Ethics?", In P. Kurtz. Ed. *Science and Ethics*. New York: Prometheus Books.
Sarukkai, Sundar. 2009. "Science and the Ethics of Curiosity", *Current Science* 97 (6).
Varela, Francisco. 1999. *Ethical Know-How*, Stanford: Stanford University Press.
Walsh, P. G. 1988. "The Rights and Wrongs of Curiosity (Plutarch to Augustine)", *Greece and Rome* 1.
Zagzebski, Linda T. 1996. *Virtues of the Mind*. Cambridge: Cambridge University Press.
Ziemke, T., Zlatev, J. and R. Frank (eds.). 1996. *Body, Language and Mind. Vol 1*. Berlin: Mouton.

For Kant's call to reason, see his essay 'What is Enlightenment'. It can be downloaded from the website:
http://philosophy.eserver.org/kant/what-is-enlightenment.txt

For a historical survey of the scientific revolution and how religion played a positive role in it, unlike popular perception, see:
Henry, John. 1997. *The Scientific Revolution and the Origins of Modern Science*. London: Macmillan.

Needham's monumental work on China:
Needham, J. et al. 1954–2010. *Science and Civilization in China*. 27 Vols. Cambridge University Press.

VII

Success and Limitations of Science

Explaining the Success of Science

Understanding science is also to understand its success and to explain this success. Why exactly is science successful? This question by itself is too broad, for the success of science is at many different levels. It has been successful in the domain of knowledge so much so that it has become the model for 'rational' knowledge. It is highly successful in the domain of application; no other human activity comes close to this conversion of theoretical knowledge to practical application. Science has also become a very successful enterprise, in the social and political domains. It is one of the most successful examples of sustained institutionalisation. Any comprehensive attempt to understand science has to explain why there is success at these different levels.

Predictive success

Consider the success of science in its knowledge making activity, the epistemological success of science. How is this success manifested? By most forcefully becoming a model for many other disciplines to the extent that many new disciplines attach the 'title' of science in order to legitimize themselves. Why is this particular mode of knowledge creation so successful? In the earlier chapters we saw what was unique about scientific knowledge. While there are attempts to reduce science to scientific method, logic or mathematics none of them can really explain the epistemological success. In fact, the

success of the scientific method is itself dependent on the predictive capacity of science. Much of the seduction of the sciences is through this act of prediction, and in this sense, science shares a common space with the performative strategy of astrology.

The seduction of science through its predictive capacity cannot be reduced to or equated with scientific method. If science had never used mathematics, had presented itself as magic but could still make the predictions that turned out to be 'true' then it is quite reasonable to believe that it would have been as successful.

Related to this capacity for prediction is the propensity for control that is really at the heart of the scientific activity. Very often, prediction is an offshoot of the degree of control over a system. A useful way to understand the nature of prediction in science is by comparing scientific predictions with a TV programme guide. A TV guide gives a listing of what programmes will air even one year from a given time. Is the TV guide predicting what is going to happen in the future? After all, if I want to see what programme is airing in the evening at 8 pm I look at the TV guide and at 8 pm when I turn on the TV I find that the same programme is being shown. Should I be surprised at this prediction of the TV guide? If not, why?

There are many other events which are completely predictable. The World Cup in football happens once every four years. The date, various fixtures and the locales are known much before the event. And like magic all these events happen exactly as predicted!

We don't usually use the word 'predict' for the TV guide and for the world cup. The preferred word here is 'planned' – we would say the events happened as planned. Our life is full of plans for the future and when the plans fructify we do not think that predictions have come true. Why are all these events plans and not predictions? The fundamental reason is that in the TV guide or the football or family events we make the events happen. We are in sufficient control of the situation that it allows us to control – most often – other events in order to make something happen. When our control is lost for some reason then our planning also unravels. Such unravelling of

plans is much less when there is a collective planning so that even if individuals for some reason are not able to play their part the collective can step in. So an event which depends on an individual might not happen if something happens to the individual whereas an event in which many groups participate is more robust and less dependent on whether something happens to an individual or not. But in all these cases the robustness of planning depends crucially on how much control there is over the event.

Perhaps not so surprisingly, the predictive capacity in science is very much related to the control one has over the event. This control is manifested through the complex instrumentation, through the accuracy of measurement, through the mechanism of experimentation and so on. There is an important element of planning that characterizes scientific experimentation. Yet we do not call scientific results as planned events but as predictions. The real story is somewhere in between. The notion of prediction in science is indeed made out to be mysterious and illustrative of the power of science without acknowledging that there is an element of control which is necessary for the performance of the experiment. As in any performance, there might be unforeseen events. Every artist discovers new things in some of their performances even though the overall performance would have been well planned. In the case of the event of the world cup football, there is much that is planned but the results of the matches are unplanned and there can be many pleasant and unpleasant surprises in such tournaments. This is really the way prediction manifests itself in many scientific experiments.

So to understand the success of predictability in science we need to consider the possibility that science succeeds in creating the world it describes. Its prediction and description are primarily of what it has good control over – at least experimentally. Not all science is about predicting completely unknown events or unknown objects and properties of nature. This is more popular in physics but the case of chemistry is quite a contrast. As many chemists recognize, the essential activity of chemistry is synthesis, creating new chemicals

and compounds. It is indeed very difficult to 'build' these molecules but chemists have found very creative ways of doing this. A set up that allows them to build such complex molecules also allows them a great degree of control over these molecules which in turn increases the predictive power. Or, equivalently, this control allows chemists to 'plan' very effectively and thus aspects of their predictive power could be seen along the lines of the 'power' of efficient planning.

Much before event management became a buzzword in management, the scientists were doing it far more effectively!

Theoretical success

Why should scientific theories work? Why are they so successful in describing, explaining and unifying phenomena? We have seen earlier what theories do and how they are constructed but what explains their effectiveness? Scientists over centuries have puzzled over this question. As discussed in some detail in the earlier chapters, mathematics was isolated as the most essential element of scientific theory. The fact that mathematical theories were successful caused enormous puzzlement to many of the greatest scientific minds. Earlier in the book, I tried to explain the success of mathematics so I will not discuss it further here.

But we also saw that theories are more than mathematics alone. If that were not so then there would be no difference between 'pure' mathematics and theoretical science. Moreover, there are various sub-disciplines in chemistry and biology where the use of mathematics is minimal. I want to describe two aspects of theories that I believe contributes to the success of the theoretical enterprise.

The most important aspect of the theoretical imagination is that in principle Anything Goes. The strength of theory comes from this liberation of theory from the way the world is. Theory combines robust imagination of all possibilities and to do this effectively theory must do many things. Firstly, it employs creative concepts to describe the 'ordinary' phenomenon. The creation of a wide range of scientific concepts is really one of the keys to the success of any theory.

Secondly, its imaginative use of the concept goes far beyond its use within a particular framework such as mathematical or logical. Scientific imagination is a creative mix of the imaginative powers of the visual, sensual, linguistic, multisemiotic, metaphorical, literary, performative and aesthetic. The strength of a theory comes from a mix of such elements and this distinguishes creative scientific thinking from other creative acts. It is this mix that allows science to privilege uncurtailed imagination as far as theorizing is concerned. The real success of the theoretical activity lies in this capacity to create as many narratives as possible. In this sense, scientific method is a way to teach scientists to make up as many stories as they want with the condition that the stories be written in a particular way. What stories eventually match the world is a question that comes much after the creation of these stories. The real success of theoretical activity is as much in the matching as in the production of multiple coherent narratives of the world.

Finally, this is possible only because science has a complex relationship with language. The way it uses and deploys language is far more complex than most other activities. This is ironic since outwardly science seems to be suspicious of natural languages but the way in which it uses graphs, figures, diagrams, symbols, ordinary words and sentences, mathematical entities and so on illustrates the powerful ways by which science uses these semiotic systems in order to create more and richer 'stories' of the world. These multiple stories are what fill countless pages of theoretical papers published week after week in all the disciplines of science. If one thought that every theoretical act is principally about the world then she would be hard pressed to explain the meaning of thousands of pages of new theoretical work published almost every week.

In the same spirit, the tinkering of experimental setups also lead to very creative output. Both theoretical and experimental work involve a great degree of creative and persistent tinkering, manipulating and doodling. Much of this tinkering is not inspired by prior expectations but is primarily an act of 'doing' something and

seeing what happens. Such an attitude is central to doing science and also contributes to the explanation of the success of scientific activity.

A final component that we can mention here is the intense specificity involved in theory and experimental work. This specificity is reflected in scientific work in many ways: a phenomenon is not analysed in its completeness but only in its parts. Following Galileo, there is a long tradition of choosing only the measurable concepts in a particular phenomenon for scientific exploration. In so choosing, the scientist recognizes that there are various other factors in that phenomenon but all those factors are kept aside and seen to be of no concern to scientific enquiry. This capacity to enquire into a small subset of a phenomenon is very important for science and contributes to the explanation of its success. Historically, one of the defining moments in modern science is its rejection of questions of metaphysics (and in general philosophical questions) in the act of doing science. Scientists such as Mach recognized that these metaphysical questions do not contribute to a scientific understanding and in fact could even hinder useful work in science. Not asking foundational questions is an important practice followed by scientists today. Among the first lessons which scientists teach their students is to focus on specific questions and not venture into foundational or philosophical issues within science! Rarely will we find biologists asking questions like 'what is life?' in their scientific work.

Ontological success

Scientists constantly build and create new things. They discover new particles and new phenomena. They synthesize new compounds and create new materials. Science is primarily an activity of constantly creating something new. Science opens up new worlds, whether they are the atomic world or a supersize macroscopic world. This constant creation and discovery of new entities is an important marker of science and something which is not duplicated in other fields which aspire to be a science.

Science, in any of its disciplines, is always creating or discovering

some new object. In physics, it could be the fundamental particles or black holes in the universe; in chemistry, new compounds and in biology new genes and proteins. (Even mathematics is constantly creating new mathematical concepts, new operations and new theorems.)

This constant discovery and creation of new objects is part of the reductionist approach that characterises science. Reductionism is arguably the most effective strategy of all sciences. This is a method by which objects, events or even disciplines are analysed by breaking them to their smaller parts. The belief is that we can better understand things when they are broken down to their smallest constituents. This maybe true but there is an even greater consequence of reductionism. It is that breaking something to its smallest parts allows us much greater control over it because one can always put it back in other ways. Some of the most effective interventions in science come from very clever ways of re-ordering the fundamental elements in a different way. One can see this clearly in gene technology, including the experiments on cloning.

Thus, the ontological success of science lies in its creative capacity to open up new worlds, new objects, new processes and phenomena in all its fields. Not only are new realities of the natural world manifested through science but so also are new realities associated with the technological world. For lay people in a society, technology is the real face of science (although technology has a complex relationship with science) and technological products are the new objects created by science. Very often, any discovery of new entities is followed by attempts to 'use' them in some technological product. So entities discovered by science are not like specimens in a museum; rather they are taken into the everyday world of technology.

Institutional success

The success of science cannot be fully explained without understanding the importance of institutional success that science has had. The *real* universality of science is the global reach of scientific institutions,

global award systems like the Nobel Prize, membership in global academies of science, participation in a global publishing empire and so on. These institutional mechanisms are further strengthened by strong links to the government and industry, thereby assuring the scientific community of economic and political support. Over the last century, the education system in almost all the countries has been completely dominated by science. The patronage that science has from the government and the industry cannot be underestimated. Like other community activities, science too depends almost exclusively on patronage. In most countries, it is the government which actually funds scientific institutions both for teaching and research. Most often, this is to the detriment of other disciplines and this has led to various problems of support and sustainability in subjects related to art, social sciences and the humanities.

Social success

The success of science is also in the social domain. It has managed to convince people and governments across the world that science is the most important discipline that must be supported by the society. In the public domain, scientists facilely argue for the importance of science by showing the use of technologies that are used in everyday activities. Successful marketing of mobile phones gets correlated to the success of science!

Science has been enormously successful in convincing the public about certain characteristics associated with it. In the public imagination, science (and by association, scientists) is logical and rational, is only concerned with truth, does not have blind beliefs, is not associated with ritual action, needs higher intelligence, is anti-religious, is not concerned with politics or other non-scientific activities, and so on. Parents are so influenced by this image that children are indoctrinated into science right from an early age.

One should remember that this process of institutionalisation did not happen overnight. It is a long process of consolidation at various levels. Right from the very beginning, scientists have recognized the

importance of bringing science to society. In the late 18th and early 19th century, along with the growth of science there was also a growth of popular science. Many of the leading scientists of those times wrote for the public and public consumption of science was fuelled by popular magazines. In the early periods of the establishment of science, famous scientists would often present their experiments in public. People would pay money to attend these sessions where the mystery and magic of science were communicated to them. Many of these processes were endemic to Europe, particularly England, in the early stages of modern science. This attempt to influence and enamour the public towards science continues even today. Some of the most popular non-fiction books are those by scientists which offer simplified accounts of the theories of science and discoveries of science. Scientists have always recognized that it is the public which pays for the doing of science, not directly but through the government, and that it was necessary to keep the public on its side.

The success of science with the government is primarily based on the use of science on two fronts: defence and industrialization. Science is an important agent for both and scientific institutions in most countries work with the government on both these sectors. Much of the defence work is done by scientists who are trained and recruited for this purpose. Governments have a big stake in supporting science because it supports their defence (and offence, of course!) capabilities. Without supporting science education, a nation will not produce enough scientists and technologists to take care of indigenous defence needs. So also for industrialisation. In a country like India, scientists are an essential part of the government. Almost all the major research institutions in the country are under government agencies. Many of them are part of the defence establishment and many others of the nuclear establishment. Today scientists are integral part of any security initiative and are members of the advisory group to the Prime minister. Thus, their capacity to negotiate better deals for science increases due to this proximity to the government. On the flip side, scientists, particularly in India, are pro-government in

general and are not able to be critical of the government on any issue since they are so dependent on the patronage of the government. This act of being neutral *vis a vis* the government is also a way to ensure the success of science at the political level.

Limitations of science

There are some inherent limitations of science. The activity of science is fundamentally geared towards describing and explaining nature. Its mode of description and explanation arises through control: we best explain what we have control over. It requires not just control over the physical world but also over language. The knowledge it creates is intrinsically linked to the nature of control. Contemporary science, which has moved quite far away from the earlier models of analytical science, is much more illustrative of this trend. In fact, chemistry and biology, and various sub-disciplines of physics, are primarily about the world they create and not about a given world. This means that there has to be a capacity to generate this world and this capacity also allows science to describe and explain it far more effectively.

This by itself is not a limitation of science. For, this is the way science is. It is one way of exploring the universe. The problem arises when this 'method' and 'worldview' are transplanted to other kinds of knowledge systems. Intervention, manipulation and control cannot be the way to knowledge for many other kinds of knowing: whether in the social and psychological sciences, in art, in certain systems of healing and health, in meditative practices and so on. What we have to realize is that these other forms of inquiry also lead to valid knowledge. It has been difficult for the community of scientists to accept these alternate forms of knowledge easily. Almost reflecting the controlling nature of their methods, scientists too try to control other forms of knowledge production. What they often forget is that scientific method and practice are based on many presuppositions – many examples have been discussed over the length of this book. There are problematical assumptions that underlie the theoretical and experimental activities. It might not be possible for other kinds

of knowing to appropriate these assumptions as well. This approach of looking at the world entirely through the prism of science is called scientism and in general scientists do demonstrate an inclination towards scientism.

A few of these assumptions – whether they are about mathematics, about abstract entities, about its view of nature and the place of the human within it, about its assumptions about the body and 'mind' – illustrate how science uses a variety of beliefs upon which it builds its empire. Even modelling has problems, as amply illustrated when modelling is blindly used to model societies and human actions. Modelling, while it has had its share of great success, depends on creating ideal situations or on creating situations which are not about how the world is but about what kind of model the scientists have control over. Models – primarily mathematical and quantitative ones – are one way of representing reality. There are other kinds of representing; there are also situations which cannot be modelled the scientific way.

Today some argue that science cannot continue with its bulldoggish way of conducting itself in society. Science is notorious for ignoring its history. Students of science do not study original texts, they have little idea of the way basic concepts in science have evolved, they have almost no idea of the complex philosophical assumptions behind these concepts and in general reject cultural and social factors in the creation of scientific knowledge. While scientists had good excuse to do this before, mainly because this work in science studies had not yet been done, now there is no excuse. Understanding its history and sociology will make scientists not only far more responsible citizens of the world but it will also enrich their creativity and lead to new forms of science.

Part of this mentality is its refusal to engage seriously with ethical issues as discussed in the previous chapter. When it comes to personal and social responsibility, science has a way of washing its hands off. It washes its hands off when there are calamitous consequences of modern science. It does this by placing the blame on other agents such

as politicians, inefficient government and so on. As long as science is dependent on the patronage of the state and as long as it is a partner in the project of national development, it has to take responsibility at different levels. The problem is many national science establishments want to have a say in the way modern society is constructed but do not want to share accountability. Science exemplifies this at many levels: power without accountability. And they have generally got away with it until recent times.

One of the real blindspots of science has been its resistance to multiculturality. In attempting to promote universalism as a major element of science, there has been a conscious attempt to erase all elements of the individual and the cultural within the project of science. More than the epistemological consequences of this action, there are serious implications as far as non-Western civilizations are concerned. And the sad part of this is that scientists in the non-Western countries have bought into this story and conduct themselves in manner reminiscent of colonized minds. These scientists are the first to promote universalism, the first to imitate science done in the successful Western countries, the first to reject any engagement with alternate knowledge systems and so on. The universalism of science is made possible only through the agency of cultural colonialism. This is a limitation that needs to be urgently addressed.

Finally technology. Much of the social face of science is technology. Much of the ills I have described above could be ascribed to technology. And many scientists do this often – they transfer the blame to technology and argue that it is not really a 'problem' of science. I cannot discuss the larger question of technology in this book for there is so much that has been written about technology that now there is a separate field called 'technology studies'. I will only make one comment here: science is in an illicit relationship with technology and it has to accept this relationship as such. It is in an illicit relationship in the sense it uses technology when it is convenient – for example, to project the importance of science and the power of science – but washes its hands off when the first

problems with technology surface. Scientists, when required, project technology as if all technology is an offshoot of science and the scientific method while that is really not the case. It is in an illicit relationship with technology because technology is the handmaiden of powerful governments and corporations, and science needs the patronage of both. Because of this patronage, it often remains a silent spectator to political corruption as well as political atrocities. Scientists often ask why they should be interested in changing society and politics when countless other people are not expected to. The reason is simple: scientists are seen as the agents of change in a society; they supposedly embody intellectual and moral virtues of democracy, equality and freedom. After getting political and social support for these virtues, they cannot suddenly wash these virtues away and say that they too are like other ordinary citizens.

The point is that the larger society is often taken in by the glamour of science (as reflected mostly in technological gadgets). But there is a huge price which the individual, the society and the culture pays for being a party to the creation of a scientific, technological world. As a global community, we are in the midst of this creation, whether we like it or not. But we need to be aware of the costs of this dream. Not just economic costs but the cultural and environmental costs. We have reached points of no-return in various ecological disasters; we cannot afford to do this without any checks and balances any more. We cannot, as many scientists visualize, colonize the moon or other planets once we destroy this planet that we reside on. We cannot blindly accept the powerful relationship between science and commerce without expecting various responsibilities from both these groups. Every time we see the glamour of science, we have to ask for the costs that go into creating the facade. This is not to deny science its due privilege but only to make it more accountable and more responsible. Such a science will be a science with a human face.

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